



EXTICE SUMMARY

Background/state of the art

Aircraft incidents and accidents have highlighted the existence of icing cloud characteristics beyond the actual certification envelope currently defined by the CS/FAR Appendix C, which accounts for an icing envelope characterized by water droplet diameters up to 50 μm (so-called cloud droplets). The main concern is the presence of super-cooled large droplets (SLD) such as freezing drizzle, in the Median Droplet Diameter (MVD) range of 20-110 μm (maximum diameter (D_{max}) between 100 and 500 μm), or freezing rain, with maximum droplets diameter beyond 500 μm . The presence of SLD was also confirmed in Europe by the European funded project EURICE. The main results raised within the EURICE 19=?? project were that, while the existence of SLD has been proved, means of compliance and engineering tools to accurately simulate these conditions were lacking and existing measures had to be improved and/or new techniques had to be developed.

International airworthiness authorities, namely the Federal Aviation Administration (FAA), Transport Canada (TC), and the European Aviation Safety Agency (EASA) intend to jointly develop and issue updated regulations for certification in SLD. The outcomes of such an international effort to improve flight safety are a comprehensive proposal for a brand new set of regulations known among insiders as “Appendix O”.

Once implemented, the proposed new rules will require aircraft manufacturers to demonstrate that their product can safely operate in SLD environments. To do so, they will be requested to demonstrate that specific capabilities comply with the new regulation. Compliance has typically involved actual flights into natural icing conditions, as well as the use of engineering simulations of the natural environment provided by experimental means, icing tunnels and tankers, and analytical methods, namely ice prediction computer codes.

Preliminary analyses of the existing tools have demonstrated the limitations of the ice modelling capabilities, especially since these methods have been focused on representing the Appendix C icing envelope and have not been developed to account for SLD conditions. Since SLD icing conditions have much larger droplet sizes than Appendix C conditions, the current methods do not adequately represent the droplet dynamics and icing physics associated with SLD.

Objectives

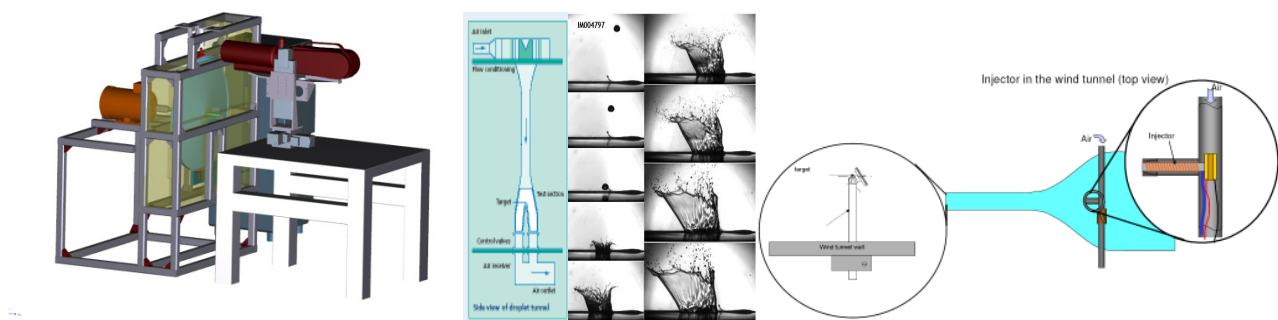
At the present time, certification authorities rely primarily on flight test data for icing certification. Unfortunately flight tests in icing conditions are costly and difficult to conduct. If standard icing condition are not easy to meet during an icing flight campaign, flight tests in extreme icing conditions, such as Super Cooled Droplet (SLD) conditions are even more troublesome. Advantages over the present situation could be achieved by performing part of the certification process through a combination of wind-tunnel testing and numerical simulation; however these approaches must be proven reliable and trustworthy. Indeed, to cover the SLD envelope, there exists a need to extend and improve existing wind-tunnel techniques and numerical simulation tools.

The objectives of EXTICE are twofold. One objective is to reduce aircraft development cost by improving tools and methods for aircraft design and certification in an icing environment. The second objective is to improve safety by providing more reliable icing simulation tools.

Description of work

In an effort to improve the reliability of simulations and to prove their accuracy, the methodology chosen is one integrating basic experiments, wind-tunnel testing and flight testing.

Basic experiments have been performed to improve SLD physics knowledge. Results from basic experiments have been used to define single SLD droplet basic mathematical model that can be implemented in ice accretion numerical simulation tools.



EXTICE SLD BASIC TESTS: Darmstadt Facility, Cranfield facility, DGA/ONERA facility

Icing wind tunnel tests on ‘industrial components’ such as a wing or an airfoil have been used both to validate and to improve numerical tools by identifying the best approach to be used for ice accretion simulation. Furthermore within the EXTICE project ice accretion was to be evaluated on a specific test article installed on an aircraft flying in icing conditions.



EXTICE industrial tests: DGA 2D tests, CIRA-IWT 3D tests, INTA flight tests

Expected results and Impact

The top-level expected result is a fundamental knowledge of the SLD ice accretion environment analysis and the development of European theoretical and experimental capabilities, the so-called engineering tools, to accurately model SLD encounter effect on aircraft in order to comply with the expected new icing certification rules. At the same time a deeper knowledge of SLD impact on aircraft has been obtained and countermeasures from SLD conditions have been investigated.

Concluding the EXTICE project allows:

- a. a decrease in time and costs for aircraft design and certification

b. an increase in aircraft safety by providing the industries with more reliable icing simulation tools

Partners

The consortium constitutes a good balance between universities, research centres and industries. Universities addressed mainly basic studies by performing both basic experiments and developing basic numerical modelling. Research centres have been charged of the know-transfer from basic research (universities) to industrial partner by implementing basic research results in industrial ice accretion simulation code. Industries, as end user, participated to validation and provided requirements and guidelines.

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Main achievements

The most important achievements from the EXTICE project are:

- A web-site has been created to present the results of the EXTICE project. This web-site contributes significantly to the goal of disseminating information gathered during the course of the project activities.
- A comprehensive literature review of the state of knowledge on super-cooled large drops was completed and a report prepared. This review provided a comprehensive summary of SLD cloud conditions and appropriate ranges for various parameters to be used during subsequent experiments.
- The basic studies of SLD physics were suitably divided between small, medium-sized and large facilities, thereby minimizing the overlap in research activities. Basic SLD related experiments (splash, break-up) have been completed and have added significantly to the pre-existing knowledge base, especially of direct relevance to aircraft icing (e.g. splash with surface roughness present, and also splash directions covering the full azimuth, rather than just in the forward direction), which was not available from previous droplet/wall collision experimental data.
- Empirical expressions were determined for the deposited mass ratio. A deterministic model of splashing up to the point of breakup was developed and a new SLD splashing model was formulated for wet surface drop impact. These studies of the basic SLD physics have thus significantly augmented the knowledge of these phenomena.
- All key experimental programs have been completed: the 2D icing wind tunnel test in DGA, the 3D icing wind tunnel test in CIRA IWT and the Flight test program in March 2012.

- A wide range of droplet trajectory and ice shape prediction codes have been successively modified by various partners. In particular, both drop splashing and rebound phenomena have been incorporated in the various codes used by the participating organizations. Some organizations have also used different formulations for these phenomena and have inter-compared them to determine which of them seems to lead to the best match with the experiments.
- Comparisons between numerical simulation and 2D data obtained in the French DGA (formerly CEPr) icing facility have been successfully completed. Both Lagrangian and Eulerian methodologies for calculating drop trajectories were employed in EXTICE with similar results. It was noted that the Eulerian method shows good promise, especially when coupled with an Euler flow code.
- The biggest improvement between code predictions and experimental results occurred for the cases with large MVDs when splashing algorithms were employed, however, the effect of SLD modifications in the various codes appeared to be small in some cases, but in other cases showed a significant improvement. At higher Mach numbers, the models failed to accurately predict leading edge ice accretion amounts and the losses due to drop splashing seem to have been underestimated. This was particularly true at warm temperatures and it was not known whether this was a SLD specific feature or a general limitation in the icing prediction codes. This would suggest that further work on ice accretion code modeling is required in the future.
- The 3D experimental data (CIRA tests) were only gathered during the final stages of the project and only a partial numerical-experimental validation has been performed. A code comparison against a subset of core cases have been successfully achieved. All codes predicted a similar large difference in ice thickness with respect to experimental data for one run but were fairly good on all of the other cases. It was underlined that one critical test condition ($MDV = 165 \mu m$) has to be addressed due to under-estimated of drop size that imply a non correct evaluation of the LWC at high diameters with existing instruments. This condition proves that the limitation of the instrumentation for SLD facility calibration is one of the key aspect that needs to be addressed.
- While ice shape predictions provided good results for the cold cases, at warmer temperatures none of the codes utilized were able to demonstrate an ability to predict the feathers and scallops observed in the experiments.
- It appears that the application of 2D techniques to the 3D cases were relatively successful, leading to the conclusion that the 3D experiments did not lead to strongly 3D effects except on the trailing edge of the extended slat.
- The organizations running the experimental facilities have been amongst the first in the world to implement capabilities to simulate the bi-modal drop size distributions which have been observed in previous flight campaigns. Furthermore, the experiments which were performed were able to quantify the importance of this capability.

Future Steps

- It would be beneficial to perform additional numerical/experimental comparison of 3D tests and have a further evaluation of test results, ice shape features. Comparison of ice shapes within and outside of EXTICE test facilities should be performed.

- Physical models of splashing, bounce, and re-impingement have been developed, but additional work is still required to better assess model validity and to improve their effectiveness with a specific attention to identified critical cases.
- Some research areas requiring a better understanding have been identified: accretion physics and SLD ice feature growth, droplet impact dynamics (splashing, break-up, re-impingement), surface water transport, heat transfer, and roughness formation, high speed case. Full scale experiments on droplet dynamic before and after the impact on the model, can provide a better understanding of the physical phenomena.
- Large efforts have been made both at DGA and IWT for icing condition calibration in SLD conditions. These icing wind tunnels, as most of the other in the world, uses different instrumentation (DGA FSSP and OAP, CIRA phase Doppler). A study on emerging measurement methods and a comparison between the state of the art of the instruments candidate to solve some SLD measurement issues, can contribute to the definition of a reference system for droplet size and concentration measurement in icing tunnels. This can allow to a future standardization of wind tunnel calibration for SLD conditions to reduce the measurements biases between the icing wind tunnels.
- EXTICE has mainly addressed freezing drizzle conditions. Further studies are required to improve the use of analytical tools and potential facility test methods for freezing rain conditions. ($MVD > 40\mu\text{m}$, $D_{\text{max}} > 500\mu\text{m}$). As we move toward the more challenging requirements for testing with SLD at higher drops diameters, there are a number of concerns that need to be addressed. Generating these large spray drops can be problematic. Concerns with droplet cooling and whether the large drops reach supercooled conditions at the test section are questions that need to be answered. In addition, the large drops may not attain the flow speed in the test section. Furthermore, high acceleration on the large droplets will inevitably cause droplet deformation. The limitations present in the current instrumentation are causing significant concern. Measuring drop size and velocity are capabilities that already have some icing facilities with phase Doppler instruments but enhancing this capability and improving the reliability of the measurements is always welcome. A high resolution, high quality imaging system to assess droplet deformation and to allow measurements in mixed phase icing cloud conditions are of great interest. The ability to measure the droplet temperature would be invaluable in assessing the quality of the icing spray cloud in the test section and would allow to evaluate and validate the droplet thermodynamic code.