Hats and pancakes in the sky: drop dynamics in high-speed flow

Supervisors: Dr. Radu Cimpeanu and Dr. Ed Brambley

On a cloudy or rainy day (of which there are no shortages here in the UK) airplanes have to navigate the local crowded airspace and fly through very humid conditions. Tiny drops of water hit the surface of the aircraft and start accumulating, forming thin liquid films which may subsequently freeze. Despite fluid mechanics being essential to the rigorous physical modelling of this complex dynamics, the methodology to predict the movement and deformation of droplets prior to impact is largely based on particle trajectory models which ignore the vast majority of the beautiful (and relevant) details of the drop dynamics - see Gent et al. (2000),[1] for a useful review. This happens primarily due to the large aspect ratio in these problems as shown in Fig. 1, but also due to product-specific designs.

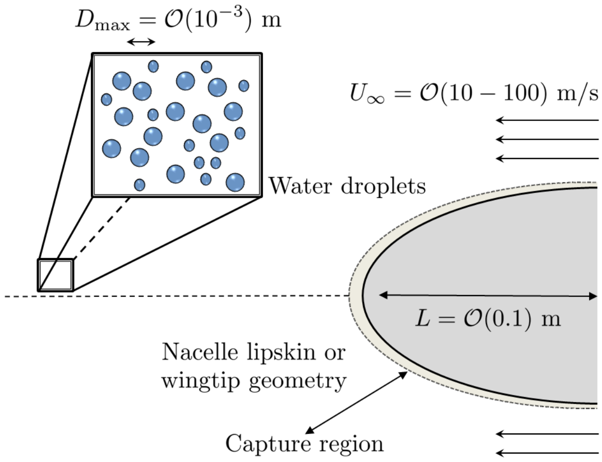

Figure 1: (Left) Aircraft flying through high liquid water content environment. (Right) Schematic of typical aircraft component such as a wingtip or nacelle lipskin interacting with liquid droplets in the atmosphere.

Recently, experimental equipment (imaging in particular) has improved to the point where capturing the details of the drop deformation prior to impact (Sor and Magarino (2015)[2]) is possible, offering useful insight for the modelling of these high speed systems. Comparisons have been made with some of the early simplified models, e.g. Clark (1988)[3], however there is significant room for improvement given the availability of data and advances in modelling techniques in the decades since.

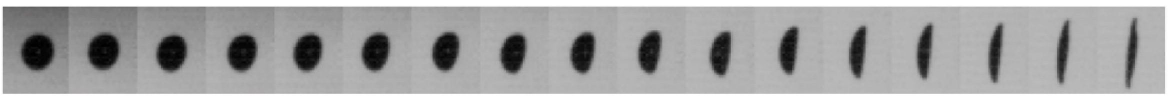

Figure 2: Drop deformation evolution[2] for a reference velocity of 90 m/s and an initial drop radius of 524 μm.

Furthermore, the project also benefits from computational capabilities via direct numerical simulations - see Cimpeanu and Papageorgiou (2018)[4] for a recent study - which would inform model testing and development. Enhancing this numerical toolkit can also become a branch of the study, which will involve state-of-the-art techniques such as adaptive finite volume methods with efficient parallelisation.

The overarching goal of the project is to go beyond traditional modelling of spheroidal (or near-spheroidal) droplets and advance towards full coupling with the background air flow, realistic drop deformation and description of the instability mechanisms that are inherent to the competition of forces in this flow. On the analytical level, progress will be achieved through a combination of mathematical modelling, partial differential equations and asymptotic analysis, as well as instability studies. However there is much to be gained from a combined analytical-numerical approach, informed by the available experimental data.

---

[1] R.W. Gent, N.P. Dart and J.T. Cansdale, Aircraft icing, *Phil. Trans. Royal Soc. A* **358**(1776), 2873-2911 (2000).

[2] S. Sor and A. Garcia-Magarino, Modeling of droplet deformation near the leading edge of an airfoil, *Journal of Aircraft* **52**(6), 1838-1846 (2015).

[3] M.M. Clark, Drop breakup in a turbulent flow - I. Conceptual and modeling considerations, *Chem. Eng. Sci.*, **43** (3), 671679 (1988).

[4] R. Cimpeanu and D.T. Papageorgiou, Three-dimensional high speed drop impact onto solid surfaces at arbitrary angles, *Int. J. Multiphase Flow*, **107**, 192-207 (2018).