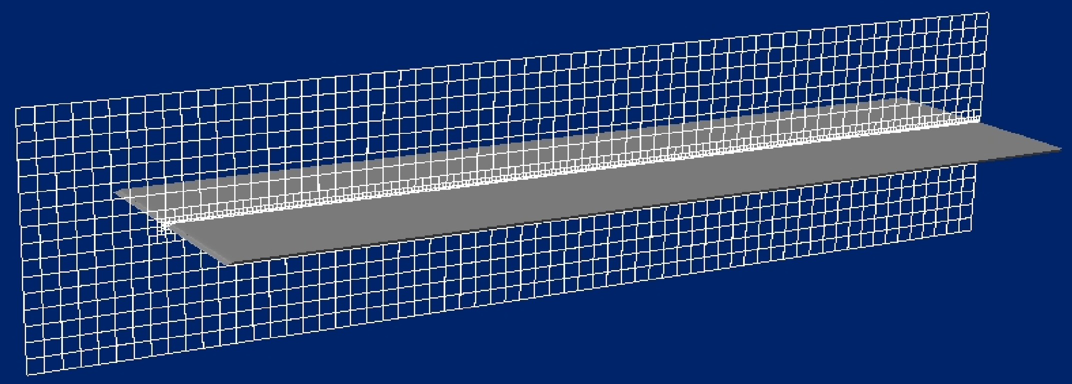


Taking the Skies by Storm: Two-Phase Flow Around Solid Bodies

Radu Cîmpeanu

AMMP, Department of Mathematics, Imperial College London

Motivation

According to the AOPA Air Safety Foundation accident database, in the last decade approximately 12% of the total number of recorded accidents in the United States occurred due to weather-related conditions.

The icing problem is responsible for 185 total accidents (48 out of which involved fatalities) in the past ten years [1].

Key Applications

In general, multi-phase flows can be found to model a vast array of both classical and novel problems. Some of the first mathematical frameworks designed for such flows focus on the Rayleigh-Taylor and Kelvin-Helmholtz instabilities.

Recently however, the interest in the aeronautic industry has shifted to problems related to icing and de-icing procedures, where two-phase flow models can address the more subtle modifications produced by coating of aircraft wings with various materials.

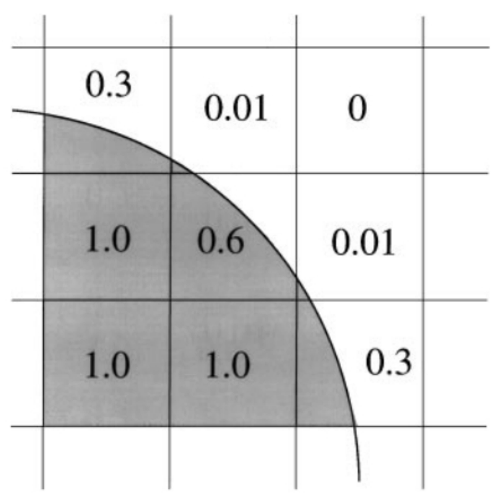
The Volume of Fluid Method

In the volume of fluid method, we use a generic function F to enable the identification of the state of a particular grid point. This can be either occupied by fluid, in which case the value of F is 1, otherwise F is set to 0. The governing equation for the advection of the interface, which can be trivially extended to three-dimensional flows as well, is

$$\frac{\partial F}{\partial t} + u\frac{\partial F}{\partial x} + v\frac{\partial F}{\partial y} = 0.$$

This partial differential equation simply describes the fact that F moves with the fluid. Overall, this method requires minimum storage requirements and accurately captures the physical effects in question.

Discretisation



We use the scalar field C_{ij}, the colour function (volume fraction, or rather area fraction if working in two dimensions), representing the proportion of the area of cell (i, j) to be occupied by phase 1:

$$C_{ij}h^2 \approx \iint_{(i,j)} F(x, y)\,\mathrm{d}x\mathrm{d}y.$$

In cells with no interfaces, C only takes values of 1 if phase 1 is present or 0 if phase 2 completely occupies the respective cell. In all other cases, namely when the cell is cut by an interface S, $0 < C < 1$, as can be seen in the figure above [2].

Introduction to Gerris

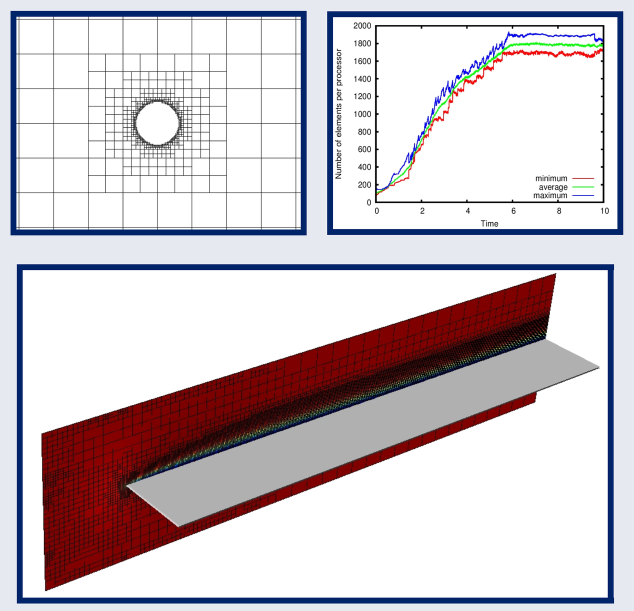
The Gerris Flow Solver is an open-source freeware package with tremendous resources in both modelling and computing power and an architecture oriented towards solving fluid flow problems. The source code is based on C and available under the Free Software GPL license. It was created in 2001 by Stephane Popinet with the support of the National Institute of Water and Atmospheric research in New Zealand and Institut Jean le Rond d'Alembert in Paris.

Computational Capabilities

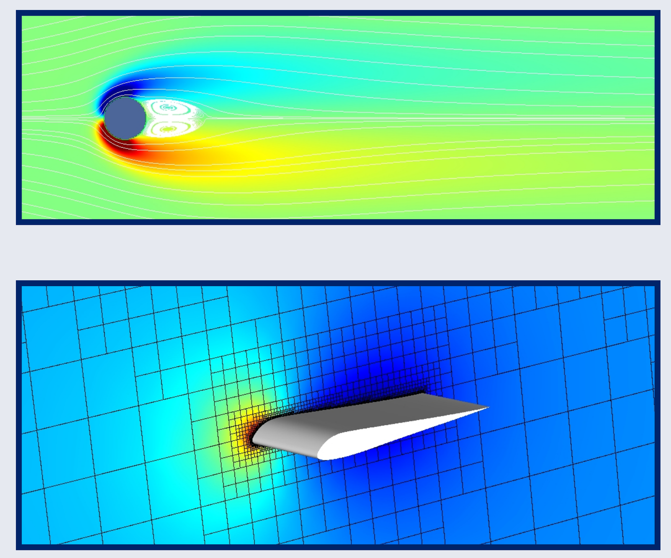
The platform provides a series of advantages:

- advanced second order finite differencing in both space and time;
- incorporation of several implementations of interfacial flows;
- selective adaptivity of specific flow parameters;
- efficient parallelisation and hence good usage of resources.

Validation and Preliminary Results



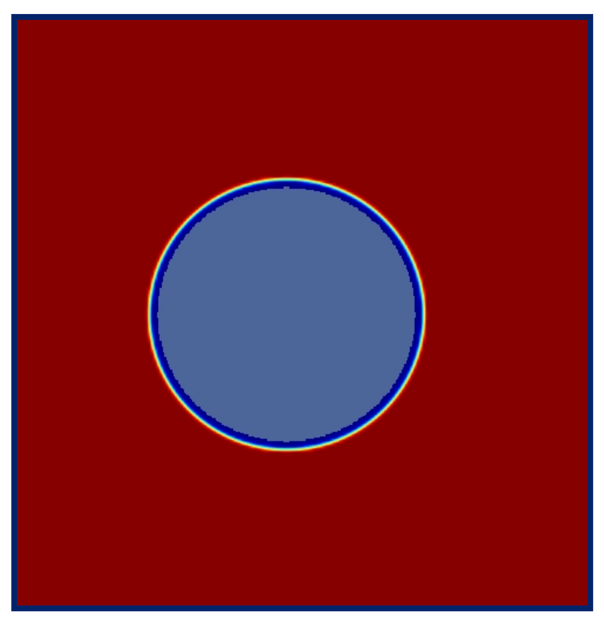
After having discussed the most relevant capabilities of the new implementation platform, it is of utmost importance to regard good scientific practice in favour of enthusiasm for performance. To this end, we engineer some numerical experiments that extend the insight into the details of the algorithms used.



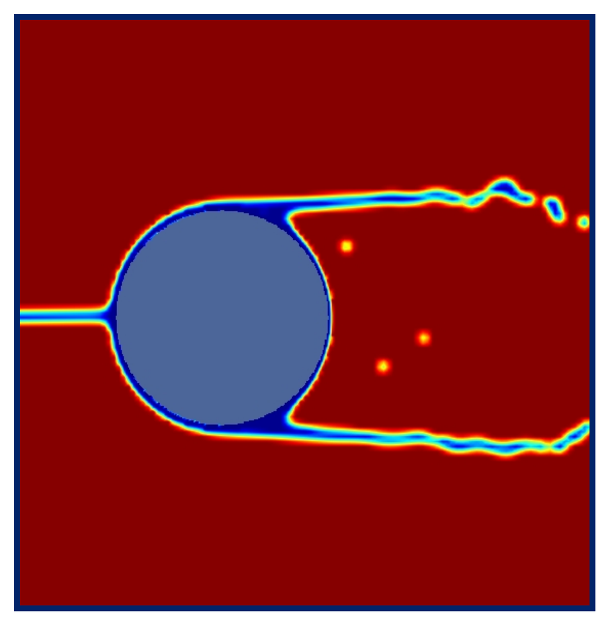
Two-Phase Flow Study Setup

The final study incorporates all the main elements tested in the previous sections in order to address the problem of two-phase flow around solid bodies.

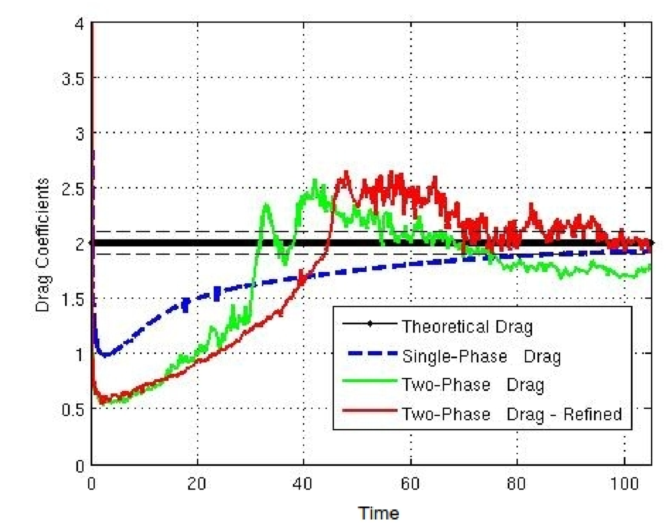
Given that in this project all foregoing investigations on solid bodies have been conducted on circular cylinders, two particular cases focused on cylindrical bodies are considered:



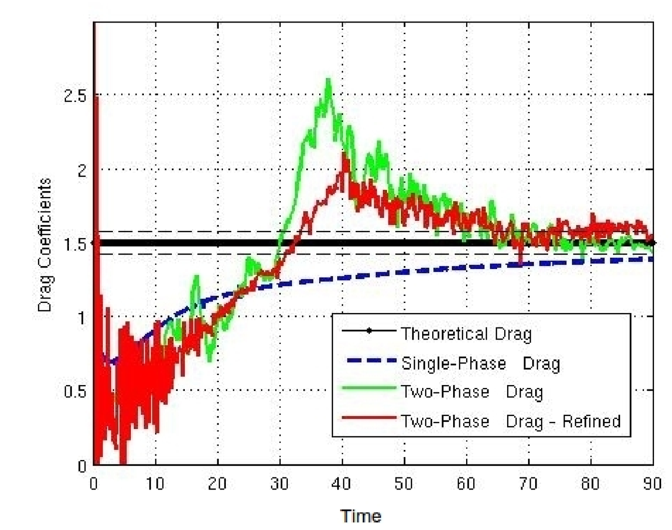
Setup 1: Water Covered Cylinder



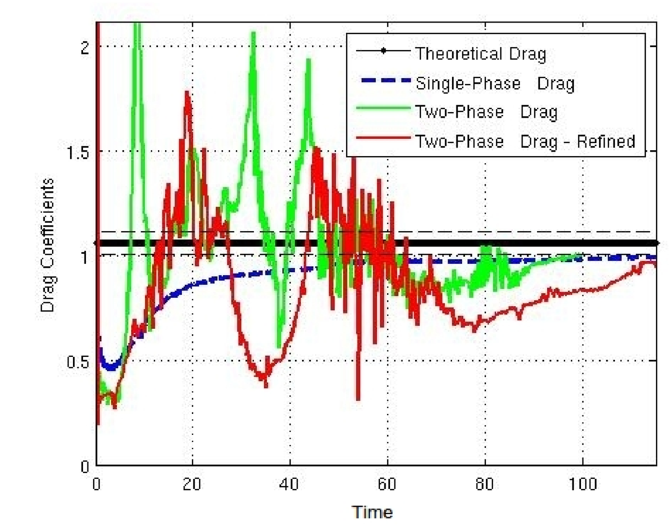
Setup 2: Continuously Fed Incoming Thin Film



Re=20



Re=40

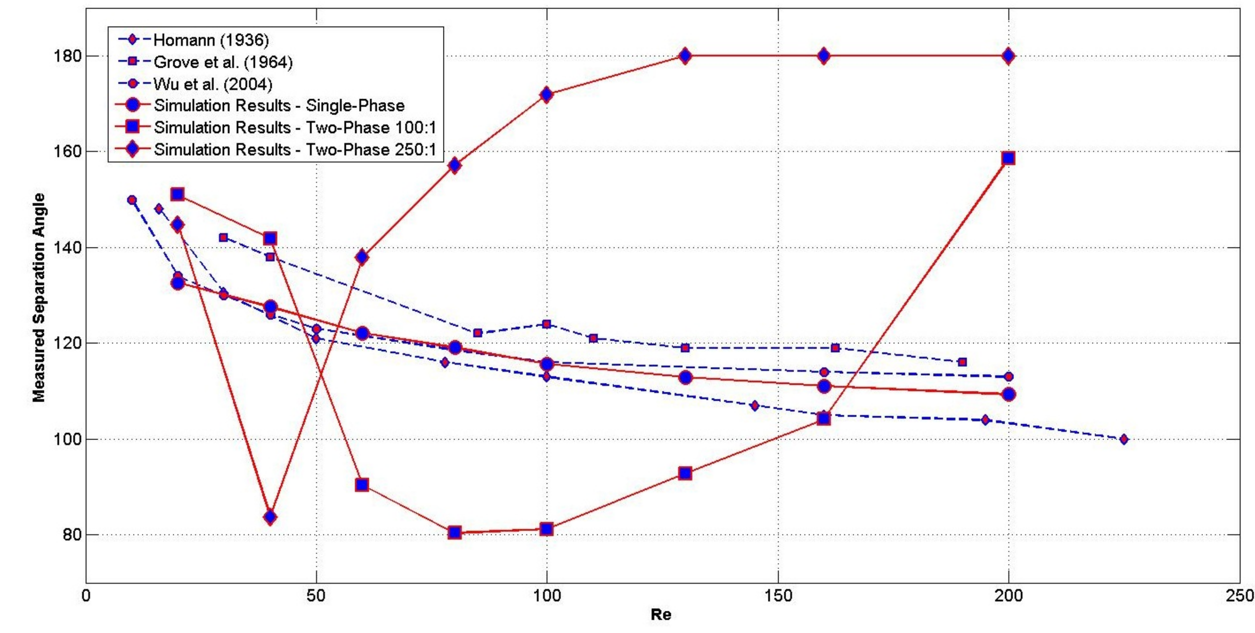


Re=100

Drag Study Results for Two-Phase Flow Around a Circular Cylinder

Findings

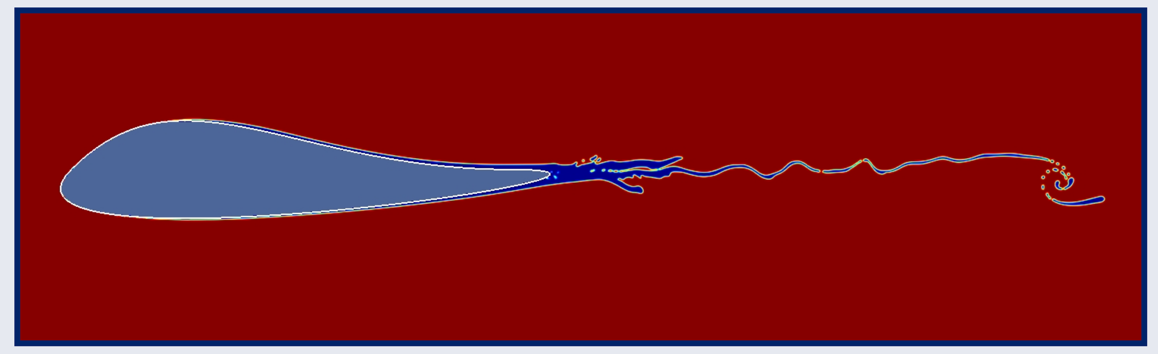
There is a significant change in the separation angle from the surface of the cylinder when realistic values are assigned to two-phase parameters. As density and viscosity ratios reach the air-water framework, not only is attachment obtained for almost all values of the Reynolds number studied, but we can also observe more severe computational challenges in the simulations.



Separation Angle Study

Coated Airfoils

The next steps in the study are related to the transition from simple solid bodies to objects with industrial relevance, such as airfoils and aircraft components in general. Simulations show encouraging preliminary results and comprehensive analytical and numerical studies will be commenced.



Conclusion

The main research question of studying characteristics of coated solids has been addressed and the machinery to extend these studies is available. Thus, so far the focus has been placed on measuring surface forces and separation angles.

However, there are many more possibilities to gain theoretical and practical insights into the nature of multi-phase flow around solid bodies. The true challenge lies in the study of airfoils and realistic wing shapes, which is not far from reach in Gerris.

References:

[1] Aircraft Owners and Pilots Association Safety Advisor Weather No. 1 *Aircraft Icing*, retrieved December 4^{th} 2011.

[2] Scardovelli R., Zaleski S., 1999, *Direct numerical simulation of free-surface and interfacial flow*, Annu. Rev. Fluid Mech., no. 31, pp. 567-603.

radu.cimpeanu11@imperial.ac.uk