INTERPLAY BETWEEN AIR AND WATER

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Abstract In the Prologue I recall, among others, the period of the Cold War in which, thanks to Polish colleagues, scientific contacts between East and West were maintained. After that, several aspects of the flow of mixtures of air and water will be discussed and illustrated by examples. Finally I will give some comments on the differences and similarities between fundamental and applied science and scientists.

Keywords: Multiphase flow, bubbly flows

1. Prologue

It is a great honour to be invited to deliver the Opening Lecture at ICTAM 2004, especially now that it is here in Warsaw, a city of great significance for Mechanics. It reminds me of the Cold War when East was East and West was West. They could nevertheless meet here in Poland, where Władek Fiszdon organized once in two years a “Symposium on Advanced Problems and Methods in Fluid Mechanics”. Participation was on invitation and those invited travelled to Warsaw and stayed there one night. The next day they were transported by bus to some place found by magician Władek where there was food and accommodation, modest but sufficient. One could meet in this way with famous Russian scientists as Barenblatt, Zel’dovich, Ladyshenskaya and others. The fluid dynamics community is greatly indebted to Władek Fiszdon for organizing these Symposia. Unfortunately, his health condition does not allow him to be here today. From this place I would like to thank him for all he did for Fluid Mechanics in this way.

The first time that I was invited to participate in such an event was in 1969 in Kazimierz (not named after my friend and colleague Kazimierz Sobczyk who will present the Closing Lecture next Friday). George Bat-
chelor was a key figure in these Symposia. He had great authority (he was a Foreign Member of the Polish Academy of Sciences), Władek Fiszdon asked his advice whom to invite and he was always very relaxed and willing to lecture on everything that he was working on. I remember very well that he gave a lecture on the sedimentation problem on which he was working at the time and what was to become the subject of his celebrated paper “Sedimentation in a dilute dispersion of spheres” [1]. This concerns the velocity with which a cloud of heavy particles sedimentates in a fluid. The, until that time unsolved, difficulty in this and similar problems is that the velocity which a small particle induces in its vicinity falls off very slowly, as the reciprocal distance from its center. The calculation of the average sedimentation speed results, because of this in not uniformly convergent integrals, with which J.M. Burgers struggled already in the 1930's. George found a way, a renormalization, to overcome this difficulty. His renormalization technique has found wide application in other areas. His presentation in Kazimierz induced me to think about the analogous problem where a cloud of bubbles rises under buoyancy.

2. Air and Water

The flow around a bubble is, to a good approximation, a potential flow. The velocity which one bubble induces in another falls off as (distance from centre to centre) \(^{-3}\). In contrast with the falling particle inertia effects are here dominant, the Reynolds number is large. This (distance)\(^{-3}\) behaviour is faster than that with the falling particle but not fast enough to overcome difficulties with not uniformly convergent integrals. When a bubble is accelerated, the surrounding liquid exerts a reaction force on the bubble, which is proportional to the acceleration. The multiplying factor has dimension of mass and is called virtual or added mass, because in calculations it can be treated as a virtual mass of the bubble which is itself of course almost massless. It appears that this mass depends on the presence of nearby bubbles in a manner which gives rise to convergence problems. Consider \(N\) bubbles in a configuration \(C_N\) with probability density \(P(C_N)\). When there is always one bubble in the point \(r_0\), such a configuration is indicated with \(C_{N-1}|r_0\) and the corresponding probability density with \(P(C_N|r_0)\). In the course of the calculation one needs to know the average velocity in the centre of a bubble in the presence of all the others, and with respect to the volume velocity \(U_0\) of the suspension,

\[
\langle u \rangle - U_0 = 1/N! \int \{u(r_0, C_N) - U_0\} P(C_N|r_0) dC_N.
\]  (1)