Modelling of non-isothermal spray flows using a combined viscous vortex method and the Fully Lagrangian Approach

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Introduction

The most popular methods to model spray flows in engineering applications are based on the Eulerian-Lagrangian approach. However, meshless vortex techniques have been actively developed during the last years [1]. In [2] a method combining the viscous-vortex and the Fully Lagrangian [3] approaches was suggested to simulate particle-laden flows for which accurate calculations of the particle number density are required. In the present study, vortex blobs are supplemented with thermal blobs, which makes it possible to simulate non-isothermal flows. Two cases have been considered: (i) a standard benchmark – Lamb vortex; and (ii) a cold spray injected into a hot quiescent gas.

Methods

2D transient non-isothermal gas-droplet flows are investigated numerically. These flows are studied in the framework of one-way coupled, two-fluid approach [4]. The carrier phase is the viscous incompressible vapour of the droplet substance. The dispersed phase consists of identical spherical evaporating droplets; due to evaporation the radius and mass of droplets are time dependent. The study is based on the combined vortex-blob, thermal-blob, and the Fully Lagrangian Approach (FLA) to modelling transient two-phase flows, which extends the method described in [2] to non-isothermal flows with phase transitions. The carrier phase parameters are calculated using the meshless vortex and thermal blob methods [1, 5]. In the calculations presented below, the 4-th order cut-off function; 863 vortex blobs and 863 thermal blobs for the Lamb vortex; and 9600 vortex blobs and 9600 thermal blobs to model two-phase spray injection were used. The dispersed phase parameters are calculated using the Fully Lagrangian Approach [3].

Lamb vortex

The Lamb vortex flow is an exact solution for the non-stationary Navier-Stokes equations; being a standard benchmark for testing numerical codes. Firstly, the numerical method was verified against the known analytical solution for the carrier phase (see Fig. 1a, Re = 100; the Reynolds number is the ratio of the initial velocity circulation and kinematic viscosity).

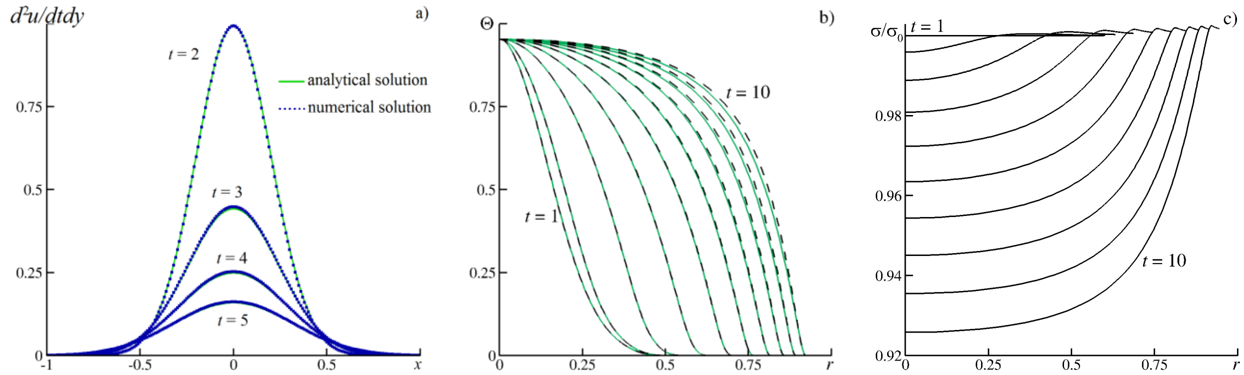

Figure 1. Time evolution of various parameters of the flow a) $d^2u / dtdy$; b) normalised droplet temperatures (solid – evaporating, dashed – non-evaporating droplets); c) droplet radii; Re = 100.

Then the case of a vortex, involving droplets and vapour in the presence of non-uniform temperature field was considered. Droplets and vapour were assumed to have the same temperature distribution at the initial time instance – Gaussian distribution with hot vapour in the far field and cold vapour in the vortex centre (ΔT = 45 K). The flow is almost the same for the evaporating and non-evaporating droplets. The difference between these two cases is more visible for the peripheral droplets at larger times (see Fig. 1b for normalised temperature; the dimensionless temperature takes values between 0 and 1, with 0 corresponding to the temperature value in the far field, 1 – in the vortex core). In the vortex core the difference between vapour and droplet temperatures is higher than at the periphery, and the evaporation is more intense in the core than in the periphery (see Fig. 1c for droplet radii evolution).

Spray flow

The second problem considered is the injection of a cold two-phase spray into a hot gas, Re = 1000 (here the Reynolds number is based on the initial maximum velocity and the inlet section); ΔT = 45 K. Three cases corresponding to water droplets with diameters 20 µm, 100 µm and 200 µm water droplets were investigated. In Fig. 2, clouds of droplets at t = 5 and t = 7.5 are presented; light colour corresponds to smaller, and dark to larger droplets. The flow with 20 µm droplets shows better mixing among the three cases considered; with the droplets forming ring-like structures. The 100 µm droplets are accumulated into a narrow band, the droplets at the band ends evaporate more rapidly than at the centre. For the conditions considered, the size of droplets with greater inertia approximately remains constant, and the droplets remain closer to the jet axis.

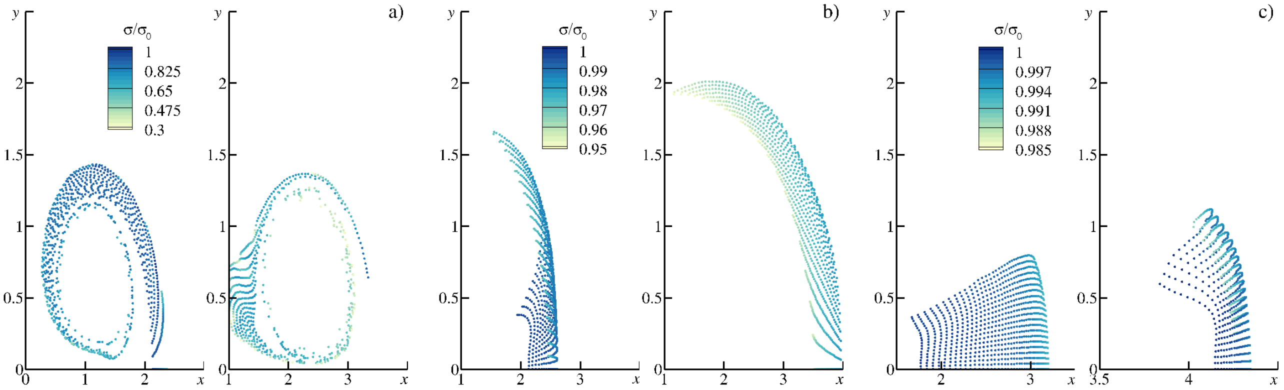

Figure 2. Time evolution of the cloud of droplets and droplet radii at t = 5 and t = 7.5; a) $\sigma_0 = 10\ \mu\mathrm{m}$, b) $\sigma_0 = 50\ \mu\mathrm{m}$ and c) $\sigma_0 = 100\ \mu\mathrm{m}$.

Nomenclature

FLA	Fully Lagrangian Approach
Re	Reynolds number
$\mathbf{v} = (u, v)$	velocity
T	temperature
σ	radius of a droplet

Subscripts:

s	droplet parameter
0	initial value
∞	value as $r \to \infty$

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