MODELLING OF INTERACTIONS BETWEEN TURBULENCE AND INTERFACE: *A'PRIORI* TESTS

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Abstract This work concernes the modelling of stratified two-phase turbulent flows with interfaces. We consider an equation for a function $\alpha(\mathbf{x}, t)$ which denotes the probability of finding an interface at a given time t and a given point $\mathbf{x}$. A model for the unclosed terms in this equation has been proposed, the performance of this model is investigated by *a'priori* tests.

INTERMITTENCY REGION

In the present work we investigate stratified turbulent air-water flows. Due to the presence of the interface the surface-normal component of velocity is damped and a redistribution of the Reynolds-stress tensor components is observed. This damping effect depends also on the r.m.s. of the surface elevation, i.e. on how the interface is deformed by the turbulent eddies. This dependence cannot be reproduced by the classical Reynolds-averaged (RANS) turbulence models which take into account only the "mean position" of the interface.

An alternative approach applicable for both RANS and Large Eddy Simulation (LES) models was proposed in [2] where a "mesoscopic" level of description was used. Therein, we considered an intermittency function α which denotes the probability of finding the water phase at a given point of the flow. The starting point is the averaged equation for the position of the interface

$$\frac{\partial \alpha}{\partial t} - \langle \mathbf{u} \cdot \mathbf{n} \rangle_s \Sigma = 0 \tag{1}$$

where $\mathbf{u}$ is the velocity, $\mathbf{n}$ is the surface-normal vector, $< . >_s$ is the so-called surface mean, cf. Ref. [1], i.e. the operation of averaging at the surface position only

$$\langle Q \rangle_s = \frac{1}{\Sigma} \int\int \langle Q(\mathbf{x}) \delta(\mathbf{x} - \mathbf{x}_s(\lambda, \mu, t)) A(\lambda, \mu, t) \rangle \, \mathrm{d}\lambda \mathrm{d}\mu \tag{2}$$

where $A(\lambda, \mu, t)\mathrm{d}\lambda\mathrm{d}\mu$ is a surface element. The surface is parametrized with a 2-dimensional coordinate system (λ, μ). The term $\mathbf{x}_s(\lambda, \mu, t)$ denotes a point at the surface and finally, Σ is the surface-to-volume ratio [1]

$$\Sigma = \int\int \langle \delta(\mathbf{x} - \mathbf{x}_s(\lambda, \mu, t)) A(\lambda, \mu, t) \rangle \, \mathrm{d}\lambda \mathrm{d}\mu. \tag{3}$$

After averaging Σ over an arbitrary volume V one obtains the local mean surface area contained in th volume V.

We proposed to use an eddy diffusivity model:

$$\langle \mathbf{u} \cdot \mathbf{n} \rangle_s = -D_t \nabla \cdot \langle \mathbf{n} \rangle_s \, . \tag{4}$$

Further mathematical transformations using an exact mathematical relation $\Sigma \langle \mathbf{n} \rangle_s = -\nabla\alpha$ lead to the formula

$$\frac{\partial \alpha}{\partial t} + \mathbf{u} \cdot \nabla \alpha = D_t \nabla^2 \alpha + D_t \langle \mathbf{n} \rangle_s \cdot \nabla \Sigma. \tag{5}$$

The first RHS term denotes the diffusion of α, our hypothesis was that that the role of the second RHS term is opposite, i.e. it causes contraction of the α profile towards the Heaviside function. The physical meaning of the two terms is connected with two competing mechanisms, a disrupting action of the turbulent eddies on one hand and, on the other hand, the stabilizing effects of gravity and the surface tension.

A'PRIORI TESTS

In this work we perform a'priori tests of the model (5). We study the case of a 2D eddy interacting with the interface, cf. Fig 1. The eddy reaches and deforms the interface, next, as the vorticity magnitude decreases in time, the surface stabilizes due to the action of the gravity. In the Reynolds-averaged picture we observe first that the intermittency region increases its width, and in the second stage, contracts. The surface statistics were obtained by averaging the data along

the interface (x-direction) and in time over a certain period, smaller than the characteristic time scale connected with the change of the mean quantities.
Based on the a'priori tests we found that the first and the second RHS terms in Eq. (5) (the diffusion and the contraction terms) have in fact opposite signs. During the smooting of the α function in the first stage the diffusion term dominated, in the second stage the compression term dominated. Fig. 2 presents the comparison of the model (4) with the exact term $\langle \mathbf{n} \cdot \mathbf{u} \rangle_s$ across the intermittency region during the spreading cf. Fig 2a and the contraction of the intermittency region cf. Fig 2b. In both cases a reasonable agreement is observed at least in the central part of the intermittency zone. Our further we plan is to perform a'priori tests in another geometry, and in another flow regime, that is an eddy interacting with a bubble. In that case the surface, deformed by an eddy will stabilize due to the presence of the surface tension. Further, the evolution equation for the α function (5) will be incorporated into the Navier-Stokes solver and tested for the test case of homogeneous turbulence interacting with the surface.

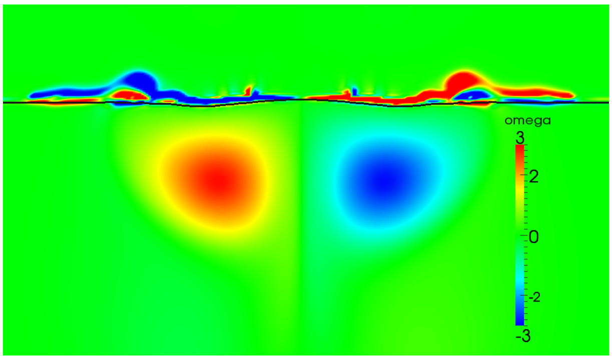

Figure 1. 2D eddy reaching and disturbing the surface.

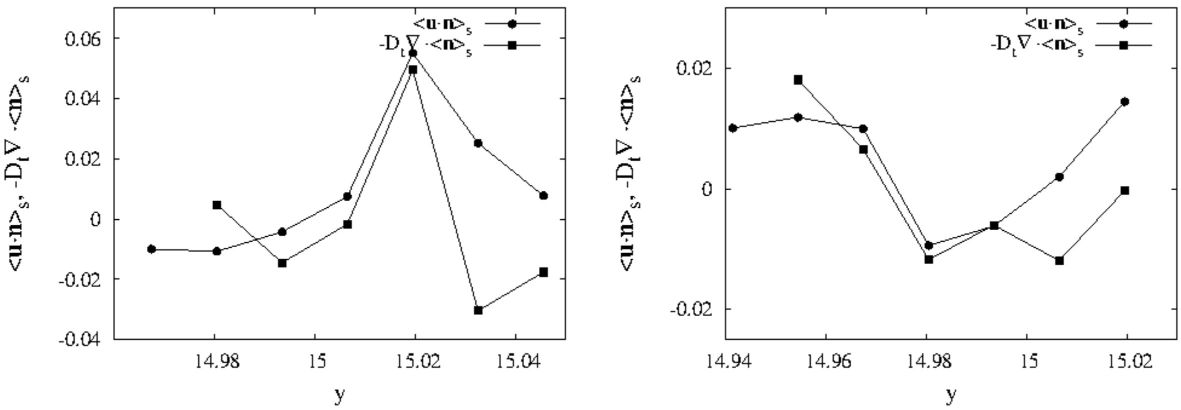

Figure 2. The performance of the model (4) during a) spreading, b) contraction of the intermittency zone.

References

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