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LETTERS TO THE EDITORS

COMMENTS ON 'MATHEMATICAL MODELLING OF BUOYANCY-INDUCED SMOKE FLOW IN ENCLOSURES'

I HAVE read the Paper of Markatos *et al.* [1] where a buoyancy affected $k \sim \varepsilon$ model of turbulence has been used for the prediction of buoyancy-induced flows in enclosures. Buoyancy affected $k \sim \varepsilon$ turbulence models have already been successfully used to calculate both vertical and horizontal shear layer flows [2, 3] but so far as I know this is one of the first attempts to predict recirculating flows with it.

The authors have introduced the influence of buoyancy only in the generation terms of the equations of k and ε, neglecting its influence in the expression of turbulent viscosity μ_t (equation (9) in ref. [1]), and in the constants σ_t (turbulent Prandtl number), σ_k and σ_ε. The authors however did not mention the value of σ_t used in their calculations.

For the introduction of buoyancy in the equation of k no further empirical information is necessary whereas its introduction in the ε-equation is a very sensible issue because the ε-equation without the buoyancy effect contains already two very sensitive empirical constants C_1 and C_2. The authors have also discussed this problem in details mentioning about the solution proposals but it is not clear to me exactly which approach has been finally used in their calculations.

It appears they have used the proposal of Rodi [4] which uses a single value of C_3 for use in the vertical and horizontal shear layers but requires different values of the buoyancy production of the lateral energy component G_{BL} (equation (18) in ref. [1]) which has a meaning only in the case of shear layer flows as has been used in refs. [2] and [3].

Thus the authors have either used the horizontal shear layer approach, $G_{BL} = 2 \cdot G_B$ with C_3 influence in it or vertical shear layer approach, $G_{BL} = 0$ for which the influence of C_3 automatically disappears.

In Fig. 10 it is thus not very clear what is indicated by the case $G_B = 0$, $C_3 = 1$, since for $G_B = 0$, $R_f = 0$ and the case is independent of C_3. Is it the case without buoyancy effect in the $k \sim \varepsilon$ model?

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REPLY TO "COMMENTS ON 'MATHEMATICAL MODELLING OF BUOYANCY-INDUCED SMOKE FLOW IN ENCLOSURES'"

THE INFLUENCE of buoyancy on the ε equation is indeed controversial. It is by no means clear that the suggestion of Rodi for S_ε is correct [1]. Consider, for example, the two definitions [1]

$$R_f = -\frac{G_B}{G_k}, \tag{1}$$

$$R_f = \frac{-G_{BL}}{2(G_k + G_B)} \tag{2}$$

and the expression

$$S_\varepsilon = C_1 \frac{\varepsilon}{k}(G_k + G_B)(1 + C_3 R_f). \tag{3}$$

Using definition (1) we have

$$S_\varepsilon = C_1 \frac{\varepsilon}{k}\left[G_k + G_B(1 - C_3) - C_3 \frac{G_B^2}{G_k}\right]. \tag{4}$$

For vertical layers, $C_3 = 0$,

$$S_\varepsilon = C_1 \frac{\varepsilon}{k}(G_k + G_B). \tag{5}$$

For horizontal layers, $C_3 = 1$,

$$S_\varepsilon = C \frac{\varepsilon}{k}\left(\frac{G_k^2 - G_B^2}{G_k}\right) \tag{6}$$

Using definition (2) we find that for vertical layers ($G_{BL} = 0$) equation (5) still holds, but for horizontal ($G_{BL} = 2G_B$) layers we have

$$S_\varepsilon = C_1 \frac{\varepsilon}{k}(G_k + G_B(1 - C_3)). \tag{7}$$

There is a fundamental difference between equations (6) and (7), depending on the sign of G_B. Thus equation (6) is always less than its value for the unmodified ($k \sim \varepsilon$) model, while equation (7) can be either greater or less, depending on the sign of the G_B.

The term involving C_3 is omitted by some workers. The resulting expression

$$S_\varepsilon = C_1 \frac{\varepsilon}{k}(G_k + G_B) - C_2 \rho \frac{\varepsilon^2}{k} \quad (8)$$

is identical to Rodi's expression for vertical layers.

We used expression (20) of the original paper [2], which has been used successfully for horizontal shear layers, but with a parametric study of C_3. Although a fixed value of C_3 is used throughout the field, maximum sensitivity to C_3 is experienced and with C_3 taking the value zero, equation (20) reduces to the above expression.

The result of the parametric study was that with our particular geometry, dominated largely by horizontal flow the effect of C_3 was small. At the time of writing the paper we had experienced difficulty in convergence of results with C_3 less than 0.3. This has now been overcome and similar conclusions apply with C_3 down to zero.

Figure 10 illustrates the effect of changing C_3 from unity (no influence of buoyancy on the ε source term) to 0.3. However, if G_B is put equal to zero, in the k equation as well (an unmodified $k \sim \varepsilon$ model), then a substantial change does occur.

Our current practice in the 3-dim. version of the mode [3] is to use the dissipation equation unmodified. The reason for this is that in the dissipation equation, the influence of buoyancy is to introduce a term proportional to the dissipation term in the heat flux equation; the term is negligible provided the fine scale motion remains isotropic. Numerical experiments with the dissipation equation modified and unmodified produced nearly the same results.

Finally, the influence of buoyancy on μ_t is incorporated through k and ε in its definition, equation (9). However, no influence has been included on σ_k, σ_ε or σ_t. The value of σ_t has been taken as unity.

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