MODELLING COMPRESSIBILITY EFFECTS ON FREE TURBULENT SHEAR FLOWS

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1. BACKGROUND

It is well established from experiments of the turbulent mixing layer between a moving and a stationary stream that, as the Mach number of the moving stream is progressively raised above 0.5, there is a rapid diminution in the layer's rate of spread. More recent experiments of Papamoschou & Roshko [1] suggest that, in general, the net effect of compressibility could be correlated in terms of the convective Mach number, M_c, irrespective of the ratio of velocities and densities of the two streams. The present project has explored what changes would be necessary to the 'new' UMIST closure in order that this model should mimic the observed behaviour.

2. THE APPROACH

The candidate processes for exploring the effects of compressibility have been taken as the mean-strain part of ϕ_{ij} and the sink term in the ε equation as suggested by direct simulation data of compressible isotropic turbulence [2]. The standard cubic form of ϕ_{ij2} is extended to the case of compressible turbulence ($\partial u_i/\partial x_i \neq 0$) as follows. As usual, the integral

$$\frac{1}{2\pi}\int \overline{\left(\frac{\partial u_\ell}{\partial x_k}\right)' \frac{\partial u_i}{\partial x_j}} \frac{dVol}{|r|}$$

is simply denoted $a_{kj}^{\ell i}$ and the process ϕ_{ij2} takes the form

$$\phi_{ij2} = k\left(a_{k\,j}^{\ell\,i} + a_{k\,i}^{\ell\,j}\right)\frac{\partial U_k}{\partial x_\ell} \tag{1}$$

Since we are dealing with compressible flow, the constraint $a_{ki}^{\ell i}$ applicable in incompressible flow is replaced by

$$a_{ki}^{\ell i} = F_1\left[2\delta_{\ell k} + a_{\ell k}\right] \tag{2}$$

which leads to an additional pressure-dilational contribution to the turbulence energy equation of

$$F_1\left[\frac{8}{3}k\frac{\partial U_i}{\partial x_i} - P_{ii}\right]$$

Here the parameter F_1 is taken as a function of turbulent Mach number $k^{1/2}/a$; the form chosen is

$$F_1 = 1.5M_t^2 \tag{3}$$

The coefficient of the sink term in the dissipation rate equation, $c_{\varepsilon 2}$, has been amended by the inclusion of a further function of turbulent Mach number

$$c_{\varepsilon 2} = \frac{c_{\varepsilon 2\,inc}}{F_2} \quad \text{where} \quad F_2 = 1 + 3.2M_t^2$$

3. RESULTS

Computational results for three types of compressible mixing layers are shown in Figs 1-3. First Fig 1 shows the case where one stream is at rest. The rapid drop-off in the spreading rate as M is raised is well captured including the levelling off of the curve for M > 5.0. Corresponding data for the case of two moving streams, shown in Fig 2, also indicate broadly correct trends though apparently the drop-off around $M_c = 0.7$ is insufficiently abrupt. Finally Fig 3 involves the mixing of streams of different gases involving density ratios up to 6:1; again the model captures most features of the reduced spreading.

4. CONCLUSION

Two simple empirical modifications to UMIST's second moment closure for free shear flows account reasonably well for compressibility effects in free shear flows.

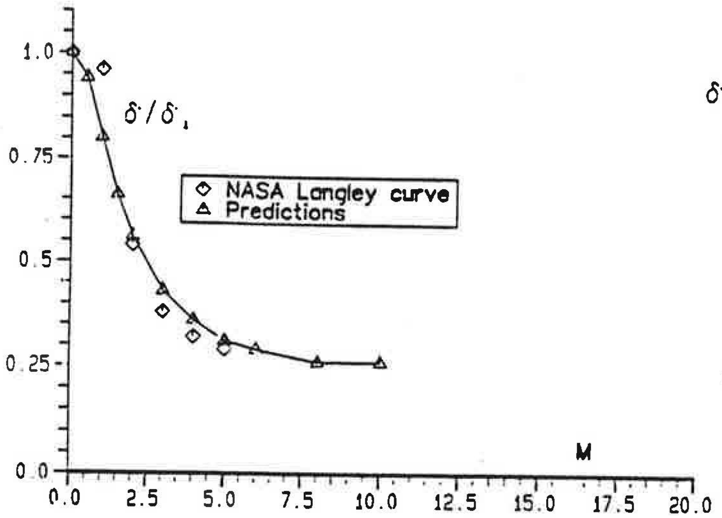


Fig 1 Spreading rate, single stream

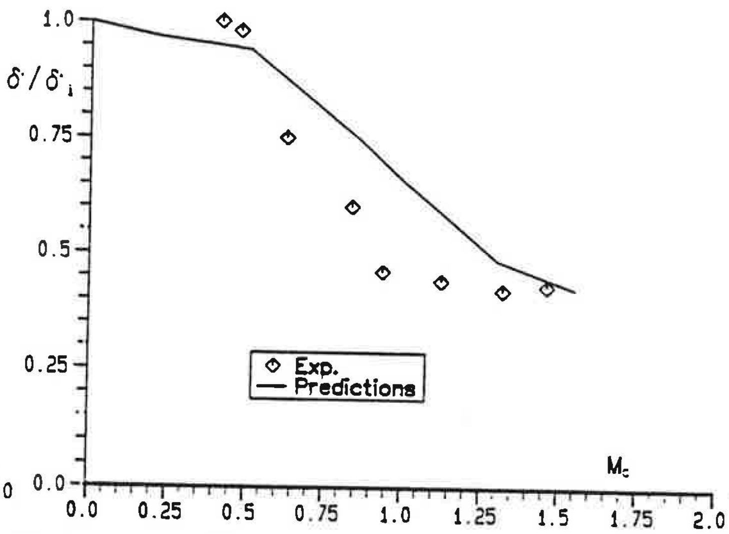
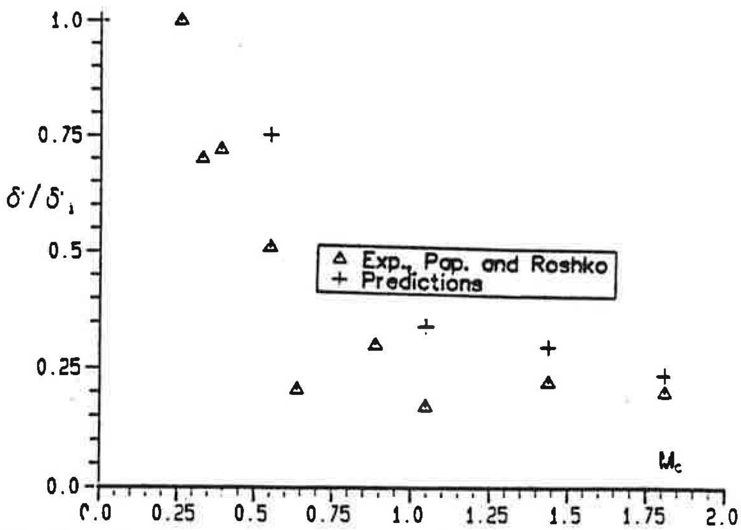


Fig 2 Two-stream, homogeneous composition cases

Fig 3 Two-stream, heterogeneous composition cases



REFERENCES

1. Papamoschou, D. and Roshko, A., 'The compressible turbulent shear layer: an experimental study', J. Fluid Mech., 197, 453, 1988.

2. Sarkar, S., Erlebacher, G., Hussaini, M.Y. and Kreiss, H.O., 'The analysis and modelling of dilational terms in compressible turbulence', Rep. No. 89-79, NASA Langley Research Center, Hampton, Virginia.