INTRODUCTION

The development of computationally based methods for calculating the properties of turbulence combusting flows in configurations of engineering interest has received continuing attention over the past two decades. The approach adopted has invariably been based on use and extension of methods originally formulated for constant density flows for which the reviews of Reynolds and Cebeci [1976], Saffman [1977], Marvin [1983], Lakshminarayana [1986], Nallasamy [1987], Hanjalic [1988], Rodi [1988] and Launder [1989] provide reasonably complete and up to date information. For complex practical flow configurations the only feasible approach remains based upon Reynolds or Favre (density weighted) averaging of the appropriate conservation equations. Direct solutions of the Navier stokes equations is not possible even for inert flows at practically occurring Reynolds numbers, Reynolds [1990], and other approaches such as large eddy simulation (LES) and vortex dynamics methods are computationally prohibitively expensive in many flows. With Favre averaging, which appears most appropriate for variable density flows, the solution of the mean velocity and mean scalar (e.g. species mass fraction, mixture fraction etc.) fields requires the density weighted Reynolds stress, $\overline{\rho u_i'' u_j''}$, and turbulent flux of scalar quantities $\overline{\rho u_i'' \phi''}$ to be determined. Recent advances in computational power has meant that the application of computational fluid dynamic (CFD) methods to complex engineering application is now quite common. A large proportion of such calculation methods utilise the $k-\epsilon$ turbulence model Jones, [1971], Jones and Launder [1972], to represent turbulent transport. In this approach the Reynolds stress is linearly related to the mean rate of strain via an eddy viscosity and while it is often capable of providing good results it does have serious limitations. In particular it is incapable of reproducing the effects of a range of phenomena important in combusting flows including, for example, the stabilising/de–stabilising influences of swirling motions and buoyancy forces, the effects of streamline curvature and variable density–mean pressure gradient influences. Generally speaking these influences act to augment or suppress individual components of $\overline{\rho u_i'' u_j''}$ and $\overline{\rho u_i'' \phi''}$ and cannot easily be embodied in an eddy viscosity formulation in a generally applicable manner. A more detailed description of turbulent transport is required and it appears that second moment (single point) closures represent about the simplest level at which this can be achieved. With such approaches all the second moments are obtained from solution of modelled partial differential evolution or transport equations. The modelled equations are obtained from their exact counterparts through introduction of closure approximations to relate higher order 'unknown' correlations to 'known' lower order quantities.

Computations of constant density flows carried out over the past five years or so have demonstrated clearly that second moment closures – even with quite simple closure approximations – represent a much more accurate method of calculating complex flows than is provided by eddy viscosity $k - \epsilon$ type models. This finding will almost certainly carry over to combusting flows though the number of reported applications of second moment closures is here much smaller and there are also additional uncertainties associated with the methods adopted to evaluate the mean density and to describe chemical reaction in a turbulent environment. While the range of flows which can be computed successfully is impressive to does need to be borne in mind, however, that the construction of a completely general model of turbulent transport is probably a chimera – it is highly improbable that closure at the second moment single point or indeed at any other currently feasible level contains sufficient information. Rather it is to be presumed that second moment closures are likely to have a limited but sufficiently wide range of applicability to be of practical value. The extent of their applicability is something which can only be determined by a careful and detailed comparison between computation and experiment.

The present article attempts to summarise progress made in devising second moment closures for the Reynolds stress and scalar flux and their extension to combusting flows through the use of Favre averaging. The approximations range from the relatively simple and widely used to current developments aimed at devising closure approximations which behave properly in the limit of the turbulence becoming two–dimensional. However, attention is restricted to high turbulence Reynolds numbers and flow near solid surfaces is excluded.