TITLE: STRUCTURE AND MIXING IN TURBULENT SHEAR FLOWS

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SUMMARY/OVERVIEW:

The broad problem being addressed in our research is to identify and describe the primary vortical ("coherent", "organized") large structures in various turbulent shear flows; to determine how they contribute to the mixing processes; and to make use of them in modelling and in possibly controlling or modifying those flows. Accumulating experimental evidence suggests that these primary vortical structures are different in different shear flows. Conclusions which follow from these views are that (i) there cannot be a universal turbulence model for these different flows; and (ii) existence of such structures implies the possibility of their manipulation or control and thus modification of the flow itself. These organized structures (and their response to excitation) are manifestations of instability response to natural or imposed disturbances and thus may be important in cooperation with other, physical processes, e.g., acoustic coupling, rate controlled chemistry, etc., in problems like combustion chamber instability.

TECHNICAL DISCUSSION

A variety of problems, using several different shear flows, have been investigated during the past three or four years. These include the following: (i) nature of the large organized structure in plane wakes; (ii) effects of a periodic disturbance on mixing in a plane mixing layer; (iii) effects of a periodic disturbance on organized structure in the shear layer of a separation bubble and the corresponding effects on bubble pressure coefficient; (iv) effect of curvature on free-shear-layer structure and mixing; (v) structure and mixing in transverse jets.

A significant result from the plane-wake experiments (Refs. 1, 2) is that the initial, quasi two-dimensional structures, which result from vortex shedding, rapidly decay; the structures that appear further downstream (e.g., observed by Taneda many years ago) are uncoupled from the initial ones. Porous cylinders which do not shed vortices eventually also develop the far-wake structures, which are a consequence of the hydrodynamic instability of the developing wake profile. A further result is that the far wake structures are three dimensional, in contrast to the quasi-two-dimensionality of the large structure in the initial vortex street and in mixing layers. This is consistent with the fact that, in wakes, streamwise and spanwise instabilities have comparable growth rates, as computed for example by Robinson and Saffman (Ref. 2).

When a perturbation of about 1% was added to the free-stream velocity of a turbulent mixing layer in water (Refs. 4, 5), the effects reported by Oster and Wygnanski and Oster were observed: enhanced growth rate in the first part of the layer I; followed by zero growth rate in a portion of the layer (II) which scales with the forcing wave length; finally relaxation to unperturbed growth rate (III). The effect of all this on mixing (chemical reaction) was studied. By and large, at high Reynolds number, the chemical production rate (i.e., mixing rate) follows the variation in growth rate; in fact, it is rather astonishing that in region II the mixing is reduced to zero! At lower Reynolds numbers, effects of periodic disturbance are complicated by the effects of the "mixing transition".

In the case of a separation bubble, originating at the shoulder of an axisymmetric, blunt faced cylinder aligned with a free stream, periodic excitation at appropriate frequencies also accelerates the initial growth of the shear layer; this shortens the bubble, reduces the pressure coefficient at separation and reduces the average pressure (drag) on the face (Ref. 6). In the reattachment region of such bubbles, the quasi two dimensional vortex structures in the shear layer develop a strong spanwise instability as they approach reattachment. Alternate segments of the resulting spanwise wave are pulled upstream and downstream, respectively; their joining segments stretch out to form a pattern of streamwise vortices which bridge the reattachment zone. In the reattached flow, the convecting wave vertex and its pair of vortex legs form a large loop, which becomes part of the resulting boundary layer structure.

For <u>curved mixing layers</u> with uniform density the sense of the curvature has a large effect, which can be attributed to Taylor-Gortler instability. When the faster stream is on the inside three dimensionality is enhanced and the pairing events so common in plane mixing layers is much less evident; growth rate is faster than in the plane layer. On the other hand, when the faster stream is on the outside the growth rate is lower. For curved mixing layers between streams of different densities, Rayleigh-Taylor instability becomes an important sometimes dominant mechanism. Three dimensionality is greatly inhibited if the heavier gas is on the outside and enhanced when the heavier gas is on the inside. Growth rates are enhanced in the latter case.

The experiments on jets transverse to a stream are done mainly in water, making use of the various available visualization and chemical-reaction measurement techniques. Results obtained include data on jet trajectories, "flame length", large structures and mixing/concentration distributions. In addition, a curious structure in the "wake" of the jet, suggestive of a vortex street, has been observed. Most of the work outlined above has concentrated on regions many diameters from the jet exit; in the continuing work the early part of the flow will also be addressed.

1. **References**

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