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RESEARCH ON AUGMENTATION OF TURBULENT MIXING.(U)
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FINAL REPORT

to

Office of Naval Research
Project SQUID

on

Contract No. N00014-79-C-0365

entitled

RESEARCH ON AUGMENTATION OF TURBULENT MIXING

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SUMMARY

The research problems studied under this contract may be grouped into the following broad categories:

A. Description of the mechanics of mixing in turbulent shear layers and the role of the large and small structure in these processes.

B. Investigation of methods for modifying and enhancing the mixing.

C. Development of experimental methods and instrumentation to facilitate the above.

D. Theoretical interpretations and models of the experimental results.

DISCUSSION

1. A powerful visualization method that was perfected is based on laser-induced fluorescence, i.e., on the use of a dye (e.g., fluorescein) which fluoresces when illuminated by (laser) light containing energy at the appropriate excitation frequency. The dye is added to one stream. The laser beam is spread out into a sheet by a cylindrical lens; this thin sheet can traverse the mixing layer in any direction to reveal chosen sectional views of the structure. Sequential pictures (movies) of these views allow one to infer three dimensional structure. Some of this was done by hand and some by image processing techniques, the latter in cooperation with the image processing group at the IBM Center in Madrid.

2. It had earlier been observed that the distribution of primary vortex sizes (or strengths) at a given streamwise location in a mixing

layer has a surprisingly broad distribution. Following the lead of Takaki and Kovasznay (Ref. 1) a theoretical model of this distribution was developed. It was found to be log-normal and to fit the experimental distributions considerably better than that obtained by Takaki and Kovasznay. The width of the distribution follows from the assumption that amalgamation of vortices is binary (simple pairing) and no empirical constants need to be fitted. From the distribution other quantities of interest, such as lifetimes, can be computed. These results are reported in Part I of Ref. 2 and are being prepared for submission to a journal.

3. Spanwise measurements of concentration distribution and fluctuation demonstrated the strong role of the secondary, streamwise vortices in the mixing process. Sectional views and three dimensional reconstruction, as described in paragraph 1, revealed the spatial structure of these secondary vortices, which produce the streamwise streaks in ordinary pictures of the plan view of the layer. Their strength is considerably greater than had been supposed; they contribute importantly to the further mixing of the fluids that have been drawn (entrained) into the layer by the primary vortices and even to the entrainment. These results are reported in Part II of Ref. 2.

4. Experiments were performed to study the possibility of augmenting the mixing action of the naturally occurring streamwise vortices by superimposing externally created streamwise vortices. The methods used to produce the latter were conventional vortex generators and also transverse jets. A transverse jet develops a pair of counter rotating vortices as it interacts with the free stream. When arranged to

interact with the mixing layer these vortex pairs enhance the mixing in the layer, as measured by the increase of reaction product in the region of interaction. The structure of the transverse jet itself was investigated. It was found that the vortex pair structure had superimposed on it a secondary, three dimensional structure which possibly contributes to mixing enhancement. A theoretical model of the transverse jet, based on the idea that at its origin it is simply a force normal to the flow, predicts the development of the vortices (analogous to vortices from a lifting wing), as well as trajectory and growth in the far field. The experiments will be reported in a thesis by D.M. Kuzo; a note on the theoretical model is being prepared for submission to a journal (Ref. 3).

5. Partially funded by this contract, experiments were carried out to study the effects of periodic excitation on mixing and its possible enhancement. The excitation was provided by superimposing a small periodic variation on the velocity of one of the streams. It is known that such excitation can have a strong effect on the primary vortices, their amalgamation processes, on Reynolds stresses and on overall growth rates. Our purpose was to investigate the corresponding effects on internal (chemical) mixing. These do not simply follow the other effects, i.e., there is not a Reynolds analogy (Ref. 4) between momentum transport and scalar mixing as would be "predicted" by most turbulent diffusion models. These experiments will be reported in a thesis by F.A. Roberts.

6. In a departure from conventional turbulent models, a new model, incorporating the experimental observations, has been worked out.

In this model the unmixed (unreacted) fluids from the two streams are dumped (entrained) into the large vortex structures where they are mixed by the secondary and smaller-scale motions. Thus the distribution of the chemical mixing is quite different from that in a gradient diffusion model; the results, e.g., for the amplitude and distribution of temperature in a reacting (combustion) shear layer are quite different from those of diffusion models and considerably closer to experimental results. The work, supported in part by this contract, has been submitted for publication (Ref. 5).

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PERSONNEL

Individuals who have made contributions to this research (and their current affiliations) are the following:

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