Digital Experiment in Spiral Turbulence

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Digital measurements in a stationary mixed laminar-turbulent flow show that the turbulent region is highly inhomogeneous and that the mean flow is highly three-dimensional.

UNDER certain conditions, the fluid motion between counter-rotating concentric cylinders consists of alternate helical stripes of laminar and turbulent flow, rotating steadily at very nearly the mean angular velocity of the two cylinders. Hot-wire measurements are being undertaken with the object of determining the local rate of energy transfer between turbulence and mean motion in a typical spiral turbulent flow, especially in the vicinity of the laminar-turbulent interfaces. The required mean values are determined by averaging over a large number of instantaneous vector velocity samples taken at corresponding points in successive cycles of the turbulence.

Some preliminary measurements leading to a choice of a particular flow for close study, and some preliminary digital results, have been reported elsewhere.[1-3] Figure 1 shows a cross section of the annulus together with the mean interface position. These data were obtained in 1964 by conventional analog intermittency techniques[1,2]; i.e., by discriminating on the amplitude of hot-wire voltage signals. The flow in question is about half laminar and half turbulent. The spiral pattern is left-handed and makes an angle of about 62° with the axis of the cylinders.

The present state of the research is that major processing of the digital data has been completed for about half of the data, covering the part of the flow near the inner cylinder. At each of about 1000 points in the pattern, a population of about 1500 vector velocity samples has been obtained. Some statistical information derived from these populations is presented in Figs. 2–4.

Figure 2 shows the mean intermittency function $\bar{\gamma}$ near the inner cylinder in detail ($\gamma = 0$ for laminar flow; $\gamma = 1$ for turbulent flow). These data were obtained by digital discrimination on variations between successive velocity samples during each traverse through the pattern. A level curve for $\bar{\gamma} = 0.5$ in Fig. 2 agrees well with the mean boundary of Fig. 1.

Figure 3 shows the tangential component of mean velocity referred to a coordinate system rotating with the turbulence. The figure suggests that gradients of mean velocity, which are needed to compute (say) the rate of turbulent energy production or the principal axes of the mean rate-of-strain tensor, are known with sufficient accuracy.

Figure 4 shows the tangential component of the normal Reynolds stress. It is noteworthy that the turbulent energy is not discontinuous across the interfaces, but increases smoothly and very nearly linearly from the interfaces toward the core of the turbulent region. This result is even more evident when the interface is sharpened, i.e., when the digital data are displaced in each cycle (before averaging) to make the intermittency factor $\bar{\gamma}$ jump form 0 to 1 at one interface or the other.

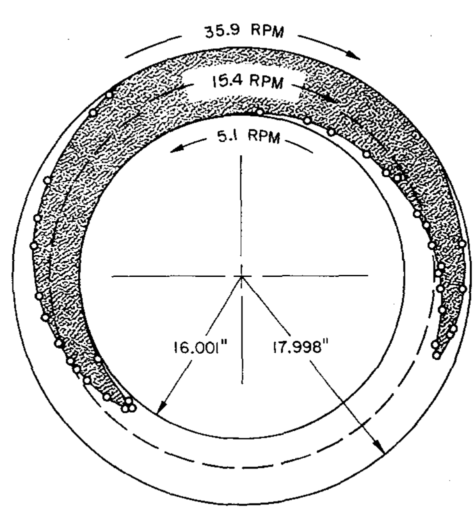

FIG. 1. Mean interface geometry (radial coordinate slightly expanded for clarity).

[1] C. W. Van Atta, Ph.D. thesis, California Institute of Technology (1964).
[2] C. W. Van Atta, J. Fluid Mech. 25, 495 (1966).
[3] D. Coles and C. W. Van Atta, AIAA J. 4, 1969 (1966).

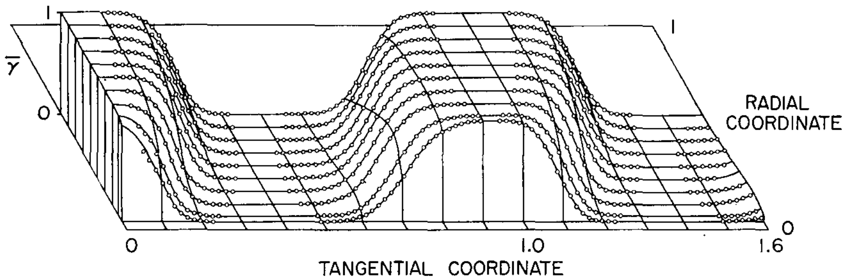

FIG. 2. Intermittency factor in coordinates rotating with the spiral turbulence.

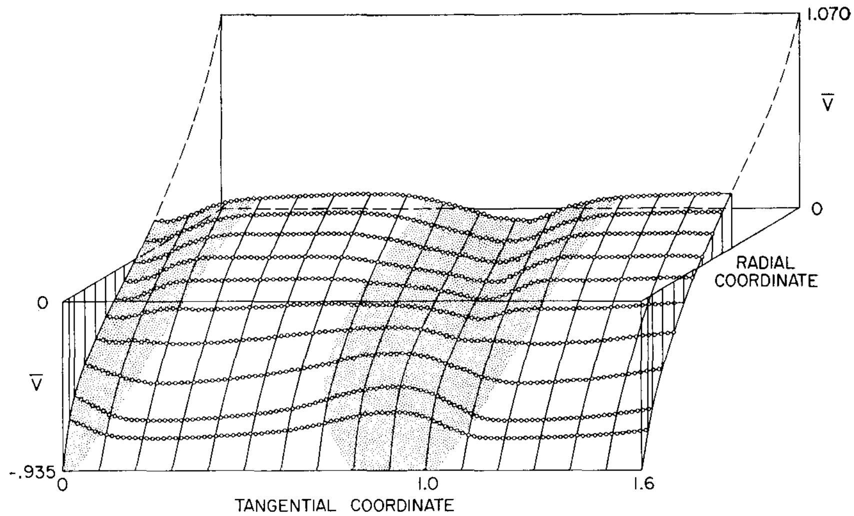

FIG. 3. Tangential component of mean velocity in coordinates rotating with the spiral turbulence. Data are normalized so that walls are moving in opposite directions with approximately unit velocity. Shaded region corresponds to $\bar{\gamma} \geq \frac{1}{2}$ in Fig. 2.

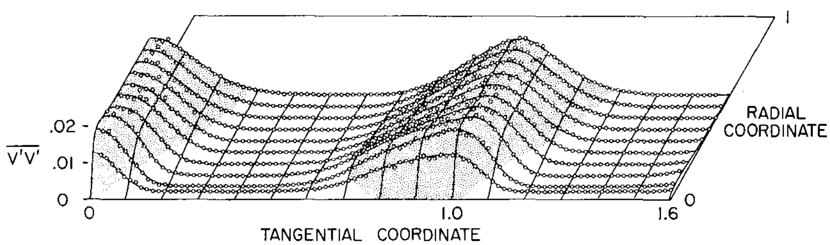

FIG. 4. Tangential component of Reynolds normal stress in coordinates rotating with the spiral turbulence. Velocity is normalized as in Fig. 3.

Several conclusions can be drawn from the results so far obtained, including the results reported in Refs. 1–3. First, the turbulence is very far from homogeneous in the turbulent region, at least at the low Reynolds number of the present experiment. Second, mean-velocity components in the plane of the mean interface may be quite large, so that three-dimensional effects are likely to be important in any discussion of interface propagation (or entrainment). Third, the spiral turbulence is now being viewed as a captive large eddy, or equivalently as a captive turbulent operator. By the terms "eddy" and "operator" is meant a flow structure processing fluid entrained from and discharged to the environment and having a lifetime long compared to the transit time for the relative motion. These conclusions, especially the last one, may be of general applicability in studies of turbulent flow.