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Turbulence Measurements in a Developing Mixing Layer With Mild Destabilising Curvature

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Summary. Single-point hot-wire measurements have been made in the developing regions of a plane and an unstably curved single-stream mixing layer. In each case the high-velocity potential flow was constrained by a solid surface to form a thick wall jet. The mean flow in the plane layer had reached approximate self-similarity before the turbulent region reached the surface at a point corresponding to the maximum length Reynolds number of 10^6 but turbulence quantities, particularly the individual normal stresses, were still changing appreciably with downstream distance. The curved mixing layer created by a convex surface had a spreading rate 9% greater than that of the plane flow with increases of 14% in the maximum level of shear stress.

List of Symbols

n	distance measured from and normal to the curved layer centreline
P	total pressure
p_a	atmospheric pressure
$\overline{q^2}$	$\overline{u^2}+\overline{v^2}+\overline{w^2}$
R	radius of curved layer centreline
r	local radius of curvature $\simeq R+n$
Re_x	length Reynolds number $U_0\,x/\nu$
R_f	curvature Richardson number defined by Eq. 1
S	rate of strain ratio defined by Eq. 2
s	distance measured from the slot along the curved layer centreline
U_0	mean velocity in the plane of the slot
u, v, w	fluctuating velocity components in the s, n and z directions
u'	r.m.s. turbulence intensity
V	mean velocity in y direction
x, y	Cartesian co-ordinates, origin at the slot lip
z	co-ordinate normal to the s-n, x-y, planes
δ	shear layer thickness defined in text
δ'	alternative shear layer thickness defined in text
θ	angle subtended at the centre of curvature of the plane wall
ν	kinematic viscosity

1 Introduction

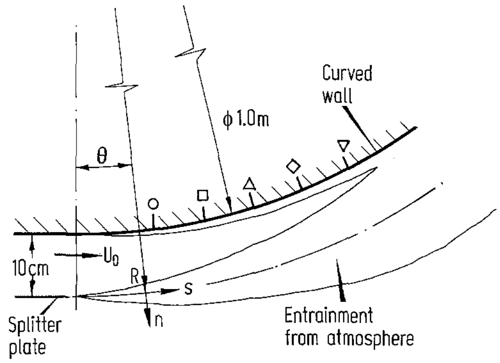
Measurements by Castro and Bradshaw (1976) in a highly curved mixing layer have shown that the effects of strong stabilising curvature on the turbulence structure may be very large. When the angular momentum of the flow increases with distance measured from the centre of curvature the extra strains introduced act to depress turbulence intensities and shear stress to levels which may be well below the equivalent plane shear layer values. These effects have also been observed in boundary layer flow on longitudinally curved convex surfaces (Meroney and Bradshaw 1975, So and Mellor 1973, Smits et al. 1979, Gillis and Johnston 1980); So and Mellor (1973) found that the shear stress actually vanished or changed sign in the outer part of a boundary layer of thickness approximately one tenth of the surface radius of curvature. The effects of stabilising curvature on turbulence are now well documented with adequate data available to test the performance of complex flow prediction methods (Gibson and Rodi 1981, Gibson et al. 1981, Gibson and Younis 1982).

In contrast, the effects of destabilising curvature have received less attention, perhaps because the results where the turbulence is augmented are likely to be less striking than when it is diminished, and because other complications arise in these flows. Thus Meroney and Bradshaw (1975) and So and Mellor (1975) found it difficult to separate and quantify the effects of curvature on concave wall flow in the presence of longitudinal vortices causing spanwise inhomogeneity.

The most detailed investigation of the effects of destabilising curvature on a free turbulent shear layer is reported by Margolis and Lumley (1965) with some corrections by Wyngaard et al. (1968). Mean flow and turbulence measurements were made in two-stream mixing layers contained in the curved working section of an open circuit wind tunnel. The results were broadly in accordance with expectations: the turbulence intensities, shear stresses and spreading rate of the unstably curved flow exceeded values of these quantities measured in a stably curved mixing layer obtained by fitting the curved working section the other way round. The effects of the bounding walls, which more recent work by Wood and Bradshaw (1982) suggest may have been significant, were not investigated. Some idea of these effects might have been formed from measurements in an equivalent plane mixing layer developing from the same initial conditions in a straight working section, which would also have established useful reference conditions for evaluating the curved flow data.

The objective of the present work was to examine the effects of destabilising curvature on mixing-layer turbulence by single-point measurement of mean flow and turbulence quantities. The development of the equivalent plane flow was also studied for comparison and it turned out that this plane layer possessed interesting features which, while they do not affect the curved-plane flow comparison, are worth documenting in view of Birch's (1980) finding that detailed turbulence measurements in the early, developing, region of a mixing layer appeared not to exist. Birch's survey appeared before the publication by Wood and Bradshaw (1982) of extensive single- and two-point turbulence measurements in a plane mixing layer constrained, as in the present experiments, by a wall bounding the high-velocity stream. Wood and Bradshaw concluded that the presence of the wall produced significant changes in the turbulence structure well upstream of the point where the flow touched the wall. Some, but not all, of the effects are reproduced in the present experiments.

It had proved to be possible to set up a curved flow without significant three-dimensional disturbances such as those observed in concave wall boundary layers by So and Mellor (1975). The degree of curvature achieved, when expressed in terms of a curvature Richardson number, was about one half of that obtained in the fully-restrained flow of Margolis and Lumley (1965), and much less than that in the stabilised layer of Castro and Bradshaw (1976). The effects of curvature, though large enough to be measured, were also substantially smaller than those in the stably curved flow, as might have been deduced from turbulence model studies.



Traverse station	Symbol	θ Deg.	s(cm) Curved	s(cm) Plane
1	○	7.5	14.4	14.5
2	□	12.7	24.4	29.5
3	△ ▲	17.9	34.4	–
4	◇ ◆	23.1	44.3	44.5
5	▽ ▼	28.3	54.3	59.5

Fig. 1. Flow geometry, notation and location of traverse stations for curved and plane mixing layers

2 Apparatus and Experimental Techniques

The mixing layer of the present work is essentially the outer shear layer of a thick curved wall jet which is insulated from the influence of the wall layer by a central potential core. The arrangement is shown in Fig. 1. Air was discharged through a slot 10 cm high by 60 cm wide accurately made from 3 mm steel plate and fitted to the 6 : 1 contraction of a conventional blower wind tunnel. The slot lip, which formed the mixing layer splitter plate, was tapered from 3 mm thickness 15 mm upstream to approximately 0.5 mm at the trailing edge. The slot flow developed on a curved wall supported by two large, plane, side plates which prevented lateral spreading and isolated the flow from external disturbances. The wall radius of curvature was set at 1.0 m after it was found that smaller radii resulted in flow separation. The region of interest, in which a potential core persisted between the boundary layer on the curved wall and the mixing layer, extended for a distance of 54 cm measured along the wall from the slot exit plane to a point subtending an angle of 31 deg at the centre of curvature of the wall.

The turbulence in a mixing layer is known to be highly sensitive to the initial conditions at the splitter plate which persist for a considerable distance downstream. There is no consensus on the optimum conditions for creating a self-preserving mixing layer. Thus Bradshaw (1966): "It is clear that turbulent initial boundary layers are to be avoided when one is trying to set up a self-preserving mixing layer" and Birch (1980): "Laminar wall boundary layers are not, in general, suitable. A fully-developed turbulent wall boundary layer would appear to be the best choice". Birch also concluded from his survey that mixing layers developing from laminar wall boundary layers became self-preserving sooner than mixing layers developing from turbulent wall boundary layers for which a minimum length Reynolds number, $Re_x = 2.10^6$, was required. However, the desirability of obtaining a self-preserving flow before it touched the wall, and of studying the effects of curvature on it, was less important than the need to minimise spanwise inhomogeneities which might be aggravated by destabilising curvature.

Preliminary Pitot-tube measurements showed that spanwise non-uniformity in the mean flow was significantly reduced when the splitter plate boundary layer was tripped. This was done by glueing a 2.5 cm strip of coarse Grade 127 sandpaper to the wall inside the contraction 28 cm upstream of the lip. The resulting turbulent boundary layer just upstream of the lip was 6.0 mm thick (to 0.99 U_0) with a momentum thickness of 0.67 mm and a shape factor 1.46. The turbulence intensity, u'/U_0, of the free stream in the plane of the slot was 0.4% at the slot velocity, U_0, of 25 m/s used throughout the experiments.

Pitot tube traverses in the spanwise direction at the different downstream traverse positions showed total pressure departures from the centre-plane value of up to 10 per cent. The larger variations appeared on the low velocity side of the mixing layer. These decayed to about one half of their original values in plane flow (when the curved wall shown in Fig. 1 was replaced by a flat plate) but increased slightly, by about 10 per cent, in the curved flow. Low speed flow visualisation with smoke revealed no trace of longitudinal vortices nor could the presence of such organised structures be inferred from any spanwise variation of the mean velocity contours.

Pitot tube and hot wire traverses were made at five stations in the central ($z=0$) plane of the curved layer, at $\theta=7.5$ deg and at four successive 5.2 deg intervals downstream. The principal quantities measured were the total pressure, mean streamwise velocity, the Reynolds shear stress and the three components of turbulence energy (normal stresses), and three triple correlations. Static pressures were measured at wall tappings. The probe traverse gear consisted of a vernier height gauge and slide, mounted on curved rails concentric with the wall and attached to the two side plates. The traverse direction was thus normal to the wall and very nearly so to the centreline of the layer. Conventional hot wire techniques were used. Mean velocity and turbulence measurements were made using 5 µm single and cross-wire sensors on DISA miniature probes with DISA type 55MO1 constant temperature anemometers. Mean velocity and streamwise turbulent intensity u' were measured in the conventional way, by reference to prior hot-wire calibration and time-averaging the fluctuating signal. Signals from the cross-wire were processed digitally to obtain the remaining components of the Reynolds stress tensor with careful checks on the $\overline{u^2}$ values obtained by both methods. The digital analysis system is described fully by Weir and Bradshaw (1974). The overall process consists of three main parts: recording the hot-wire signal on analogue magnetic tape, the analogue-to-digital conversion process which transfers the data to digital magnetic tape, and the analysis of the digitised data. The digital analysis was performed off-line on the Imperial College CDC 6400 mainframe computer. A number of independent check measurements were also made using different sensors, anemometers and the different on-line data reduction system developed by Laker et al. (1981). The results, which are denoted by solid symbols in the figures of the next section, agree closely with the other data.

3 Definitions

The thickness, δ, of the mixing layer is defined in the same way as by Castro and Bradshaw (1976) as the distance between the points where $(P-p_a)/\frac{1}{2}\varrho U_0^2$ has values of 0.81 and 0.0625. P is the total pressure measured with a Pitot tube, p_a is the atmospheric pressure and U_0 is the velocity in the plane of the slot. In a plane mixing layer with a static pressure negligibly different from p_a, and the edge velocity constant and equal to U_0, this definition gives δ as the distance between the points where U/U_0 is equal to 0.9 and 0.25. A more usual thickness definition for plane flow is the distance between the points where U/U_0 is equal to 0.9 and 0.1. Thus, to facilitate comparisons with other mixing layer data, an alternative thickness δ' is defined as the distance between the points where $(P-p_a)/\frac{1}{2}\varrho U_0^2$ has values of 0.81 and 0.01. The centreline is defined as by Castro and Bradshaw (1976) as the locus of points 0.375 δ from the high velocity edge which in the plane layer coincides with the line $(P-p_a)/\frac{1}{2}\varrho U_0^2=0.45$, $U/U_0=0.67$. It turns out that in the present experiment this arbitrarily chosen curved centreline is very nearly concentric with the curved wall and its radius of curvature can be taken as constant and equal to 110 cm.

The degree of curvature is described in terms of a parameter which corresponds to the flux Richardson number for buoyant flows. This is defined as (minus) the ratio of v-component energy production, due entirely to streamline curvature, to u-component energy production:

$$R_f=\frac{2\,U/r}{\partial U/\partial n+U/r}=\frac{2S}{1+S} \tag{1}$$

where $r(\simeq n+R)$ is the local radius of curvature and n is distance measured normal to the centreline. S is the rate of strain ratio:

$$S=-\frac{\partial V/\partial x}{\partial U/\partial y}=\frac{U/r}{\partial U/\partial n} \tag{2}$$

For destabilising curvature R_f and S are negative.

4 Results

4.1 The Plane Mixing Layer With a Constraining Wall

The plane mixing layer was set up by fitting a flat plate in place of the curved wall shown in Fig. 1. Figure 2 shows the streamwise variation of the layer thickness δ obtained from mean velocity measurements taken in the midspan plane and plotted in Fig. 3. The increase is approximately linear with a virtual origin at $x=4$ cm and $d\delta/dx=0.133$, $d\delta'/dx=0.165$. This spreading rate is about 17% greater than that measured by Castro (1973) in the plane layer generated in the curved flow rig when the backplate was removed, and some 24% greater than that measured by Wood and Bradshaw (1982) in a flow similarly constrained by a wall bounding the high-velocity stream. The discrepancies here are not altogether surprising. Both the data

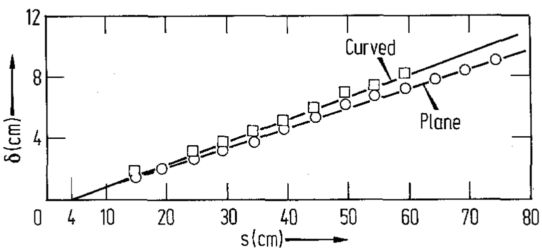


Fig. 2. Growth of shear layer thickness with distance along the centreline

reviewers, Birch (1980) and Rodi (1975), comment on the large amount of scatter in the reported spreading rates which Birch attributes to the predominance of measurements taken in developing mixing layers. Such flows at the moderate Reynolds number corresponding to the present case also tend to spread faster than the asymptotic rate when the initial wall boundary layer is turbulent. Other reported values of $d\delta/dx$ tabulated by Rodi (1975) range from 0.13 to 0.2; when the extreme values are discarded $d\delta'/dx = 0.16$, very close to present results, emerges as a fairly well supported value for $Re_x > 7.10^5$.

The linear growth, and the near-coincidence of the mean velocity profiles plotted in Fig. 3, suggest the existance of a self-preserving flow. Profiles of the Reynolds stresses and turbulence energy plotted in Figs. 4 and 5 show that this is not the case, and that the flow is still developing by the last traverse station where the mixing layer edge merges with the flat wall boundary layer to form a wall jet with no potential core. The maximum value of the shear stress, $\overline{uv}_m$, which occurs close to the centreline, increases from 0.009 U_0^2 at $x = 14.5$ cm to 0.01 U_0^2 at $x = 59.5$ cm. The centreline value of the structure parameter, $\overline{uv}/\overline{q^2}$, falls from 0.175 to a minimum of 0.13, and then rises to 0.14 at the last traverse position.

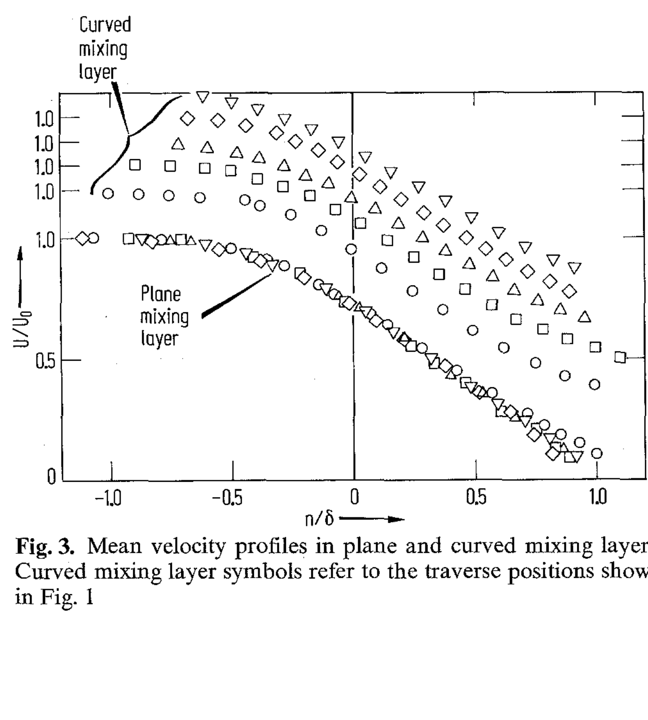


Fig. 3. Mean velocity profiles in plane and curved mixing layers. Curved mixing layer symbols refer to the traverse positions shown in Fig. 1

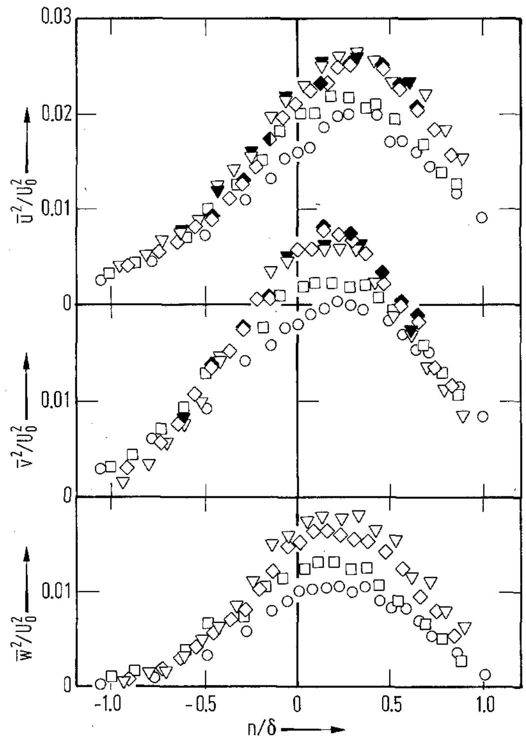


Fig. 4. Profiles of the normal stresses in the plane mixing layer. Symbols defined in Fig. 1

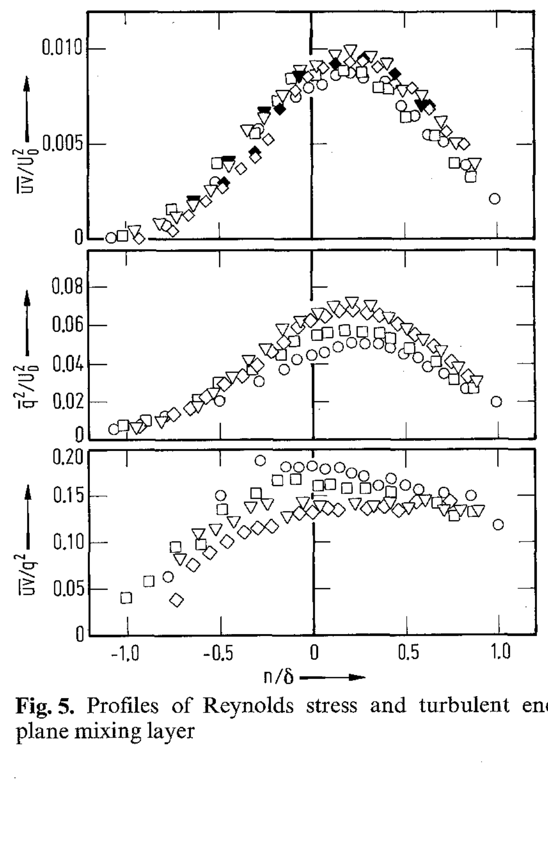


Fig. 5. Profiles of Reynolds stress and turbulent energy in the plane mixing layer

The shear stress levels are consistent with the observed spreading rate: the mean flow momentum balance gives $\overline{uv}_m = 0.0112\, U_0^2$ for $d\delta'/dx = 0.165$.

Profiles of the normal stresses are plotted in Fig. 4. $\overline{u^2}$ and $\overline{v^2}$ are nearly equal and about 50% greater than $\overline{w^2}$ in the centre of the flow. In each profile the maximum value of $\overline{u^2}$ occurs on the low velocity side of the maxima of $\overline{v^2}$ and $\overline{w^2}$, and on the high velocity side of the centreline $\overline{v^2}$ is actually slightly greater than $\overline{u^2}$. At the point furthest downstream, where $x = 59.5$ cm and $Re_x = 10^6$, and the layer nearly touches the wall, the maximum values of $\overline{u^2}$ and $\overline{w^2}$ appear to have reached roughly constant levels, with $\overline{u_m^2} \simeq 1.4\, \overline{w_m^2}$, while the peak value of $\overline{v^2}$ is falling with distance downstream. While the shear stress adjusts quickly to the asymptotic level consistent with the observed spreading rate, all the normal stresses rise gradually from relatively low levels in the vicinity of the splitter plate: $\overline{u^2}$ by 25%, $\overline{v^2}$ by 30% and $\overline{w^2}$ by 65%, contributing in total to a one-third rise in $\overline{q^2}$. The shear stress correlation coefficient on the centreline falls over the same downstream distance from 0.43 to 0.38.

These results differ in detail from the earlier data reviewed by Birch (1980) although a common feature is the tendency of $\overline{u^2}$ and $\overline{q^2}$ to approach asymptotic values more rapidly than $\overline{v^2}$ and $\overline{w^2}$. The large overshoot in the shear stress that has been observed a short distance downstream of the splitter plate in the experiments with laminar initial wall boundary layers is not found in the present experiments. Bradshaw (1966) also eliminated this overshoot by tripping the initial boundary layer. The high level of $\overline{v^2}$ throughout the developing flow is rather surprising although, as noted by Birch (1980), differences in the initial conditions are responsible for the large amount of scatter in reported values of the normal stresses. It seems improbable that this feature of the present experiment is due solely to the presence of a turbulent wall boundary layer because the effects of tripping the boundary layer, described by Bradshaw (1966), were to depress $\overline{v^2}$ relative to $\overline{u^2}$ in the near field in a mixing layer experiment where near-equality of $\overline{u^2}$ and $\overline{v^2}$ had, as here, previously been observed by Bradshaw et al. (1964). It seems more likely that the present results, which are associated also with low $\overline{w^2}$ near the lip, are due more to the characteristics of the tripping device (sandpaper), the artificially thickened boundary layer and to possible vortex formation at the edge of the splitter plate.

Changes in the normal stresses found by Wood and Bradshaw (1982) in their nominally self-preserving mixing layer, and attributed by them to the influence of the nearby wall, were a rise in $\overline{u^2}$ with x near the high-velocity edge which was partially caused by an increasing level of potential fluctuations in the diminishing potential core, and the "totally unexpected" result that $\overline{v^2}$, after being approximately self-preserving upstream, increased with x across the whole layer downstream. Neither of these effects appear in the present results.

We have considered, and discounted, the possibility that relatively low-frequency "flapping" of the flow might have contributed to the near equality of $\overline{u^2}$ and $\overline{v^2}$. The relative magnitudes of contributions make to $\overline{u^2}$ and $\overline{v^2}$ by possible flapping may be estimated by assuming a sinusoidal bodily displacement, a sin (ωt), of the mean velocity profile from its mean position. Thus $\overline{v^2}$ is augmented directly and $\overline{u^2}$ is augmented by translation of the mean shear so that

$$\frac{\overline{u^2}}{\overline{v^2}} = \frac{(\partial U/\partial y)^2}{\omega^2} \tag{3}$$

or inversely proportional to the square of an appropriately defined Strouhal number. Values of the flapping frequency high enough (of order $\partial U/\partial y$) to make this ratio unity would appear to be extremely unlikely, a view supported by Goldschmidt and Bradshaw's (1973) measurement of flapping frequency in a round jet which showed Strouhal numbers of order 10^{-2}. It is to be expected that the wall constraining the high-velocity stream would tend to damp such oscillations in the present experiments.

The remaining measurements consisted of the triple velocity correlations $\overline{u^2v}$, $\overline{v^3}$ and $\overline{uv^2}$. The cross-stream gradients of these quantities appear in the thin shear layer transport equations for $\overline{q^2}$ and $\overline{uv}$. The profiles plotted in Fig. 6 show, rather surprisingly, that within the estimated

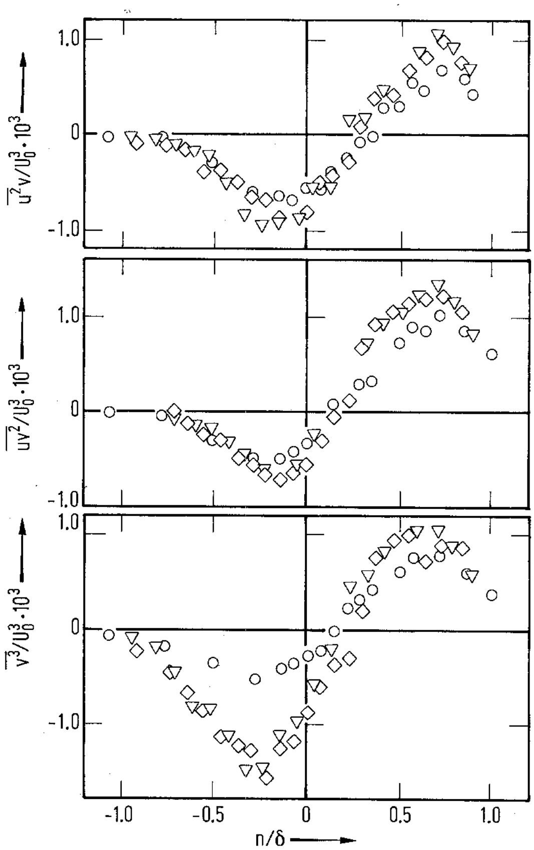


Fig. 6. Profiles of triple correlations in the plane mixing layer

experimental uncertainty of 20%, self-preservation in $\overline{u^2v}$ and $\overline{uv^2}$ appears to have been arrived at downstream. The profiles of $\overline{v^3}$ show greater changes and scatter. It is noteworthy that, while the percentage changes in $\overline{u^2}$ and $\overline{v^2}$ from the first to the last traverse positions are about the same, the turbulent transport of $\overline{u^2}$ increases only slightly with distance downstream compared with a rapid increase in $\overline{v^3}$ from very low levels close to the splitter plate.

The picture that emerges from these measurements is of a flow whose turbulence structure is strongly influenced by the initial conditions, the effects of which persist downstream until the shear layer touches the wall. The mean flow is approximately self-preserving with a typical constant spreading rate. It now remains to be seen how this simple flow is affected by the imposition of longitudinal curvature.

4.2 *The Curved Mixing Layer*

The centreline of the curved mixing layer lies almost exactly on a circular arc of radius 110 cm centred at the centre of curvature of the wall. The streamwise variation of R_f on this centreline is shown in Fig. 7. A maximum (negative) value of −0.15 was obtained at the last measurement position; this may be compared with the maximum centreline value of 0.34 in the Castro and Bradshaw (1976) flow and values of approximately −0.36 in the unstably curved mixing layer of Margolis and Lumley (1965). The results show a modest but consistent increase in turbulence levels due to extra strain generation of $\overline{u^2}$, $\overline{v^2}$ and $\overline{uv}$. The increase in mixing layer thickness δ with distance s measured along the centreline from the splitter plate lip, is plotted in Fig. 2 for comparison with the plane layer result. The growth remains approximately linear but 9% greater than that of the plane layer with $d\delta/ds = 0.145$, $d\delta'/ds = 0.179$. This increase in the spreading rate is consistent with an increase of approximately 14% in the shear stress shown in Fig. 9. Profiles of the mean velocity plotted in Fig. 3 show rather more scatter and departures from an asymptotic self-preserving form than do those of the plane layer. The normal stresses plotted in Fig. 8 again show the effects of the initial conditions persisting downstream but also show distinct trends due to the effects of curvature

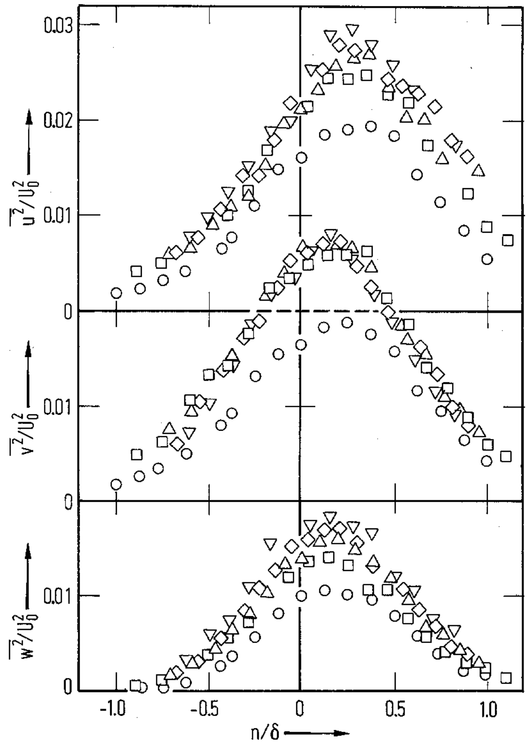


Fig. 8. Profiles of the normal stresses in the curved mixing layer. Symbols defined in Fig. 1

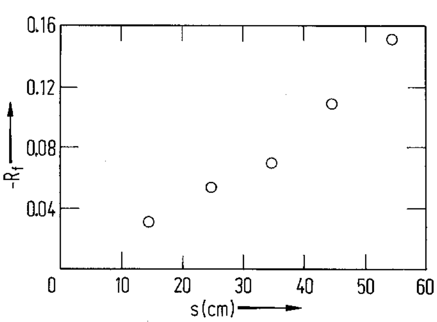


Fig. 7. Variation of curvature Richardson number (Eq. 1) with distance along the centreline of the curved mixing layer

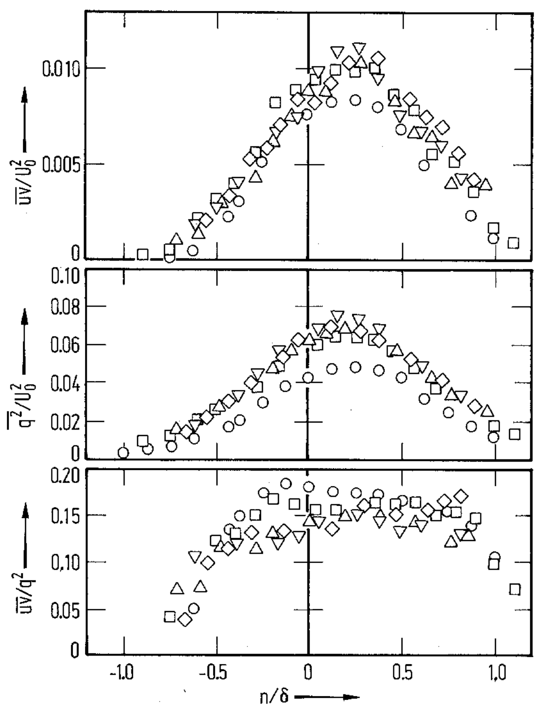


Fig. 9. Profiles of Reynolds stress and turbulent energy in the curved mixing layer

which differ from the plane layer results. The $\overline{u^2}$ profiles are slightly more scattered than those of the plane layer but show a distinct trend to increasing values with distance downstream, in contrast to the plane layer results which indicated that an asymptotic profile had been reached. On the face of it this is a rather surprising result because the direct mean strain generation of $\overline{u^2}$ is diminished, by a factor $(1+S)$, when the curvature is destabilising. Changes in the $\overline{u^2}$ production rate due to changes in the mean strain rate may, however, be more than balanced by the higher shear stress levels prevailing throughout the flow which increase, relative to plane flow, the generation rates of $\overline{u^2}$, $\overline{v^2}$ and $\overline{q^2}$. The measured behaviour of $\overline{v^2}$ is more in accord with expectation. Starting from relatively high levels due, as in the plane layer, to the initial conditions, $\overline{v^2}$ increases rapidly with distance downstream so that the last four profiles are, to the degree of experimental accuracy, coincident. Here the tendency observed in the plane flow for $\overline{v^2}$ to decrease to presumed asymptotic levels downstream is offset by direct mean strain generation in this component. In a plane shear flow energy is generated only in $\overline{u^2}$ and distributed to $\overline{v^2}$ and $\overline{w^2}$ by fluctuating pressure-strain interactions. Curvature of the streamlines introduces direct mean strain generation $4\,\overline{uv}\,U/r$ of $\overline{v^2}$ which, with measured values of uv, is responsible here for maintaining $\overline{v^2}$ at a high level.

A generally observed effect (Bradshaw 1973) of curvature on the turbulence in shear flows is that, while the turbulence energy is altered relative to plane flow by a factor $(1-S)$ the shear stress changes by a factor $(1-\alpha S)$ where α is of order 10. This empirical finding, based on measurements in boundary layers, presupposes a greater degree of anisotropy in the normal stresses than has been found in the present experiment. This can be seen from the terms in the transport equations for $\overline{q^2}$ and $\overline{uv}$ which represent mean field generation and which can be written as:

$$\text{generation of } \overline{q^2}: \quad -2\overline{uv}\frac{\partial U}{\partial n}(1-S)$$

$$\text{generation of } \overline{uv}: \quad -\overline{v^2}\frac{\partial U}{\partial n}\left[1-\left(2\frac{\overline{u^2}}{\overline{v^2}}-1\right)S\right].$$

In a typical self-preserving shear layer $\overline{u^2} \simeq \overline{2v^2}$ and the factor multiplying S in the $\overline{uv}$ generation term is about 3; in a curved wall boundary layer the presence of the wall reduces $\overline{v^2}$ relative to $\overline{u^2}$ and the factor increases to about 5, both values more or less consistent with, though lower than, Bradshaw's (1973) empirical recommendations for modifying the mixing length in curved flow. In the present experiment $\overline{u^2}$ and $\overline{v^2}$ are roughly equal as a result of the influence of the initial conditions in the still-developing flow. Consequently the extra generation of shear stress is less than it would be in a fully self-preserving layer and the increase in growth rate is less than expected.

The profiles of the triple velocity correlations which are plotted in Fig. 10 show unavoidable scatter in which it is not easy to discern trends directly attributable to the imposition of longitudinal curvature. The most noticeable changes from the plane flow results of Fig. 6 are in $\overline{v^3}$, whose gradient represents turbulent diffusion of $\overline{v^2}$, and which is of particular interest to users of second-order closure methods to model in detail changes in the turbulence. The changes wrought here seem to show a slight reduction of $\overline{v^3}$ overall combined with a flattening of the profiles, particularly on the high velocity side of the centreline where S and R_f have their highest (negative) values. These trends, if correct, suggest that the ability of $\overline{v^2}$ to diffuse away from regions of high intensity is reduced.

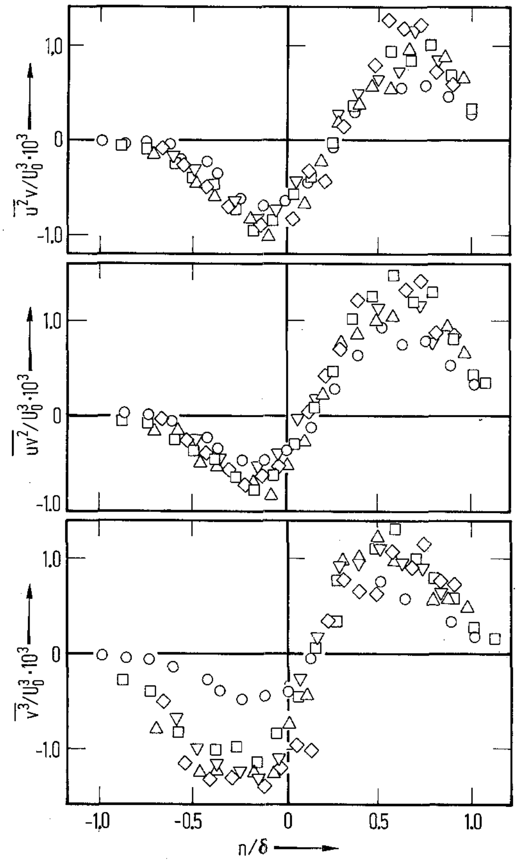


Fig. 10. Profiles of triple correlations in the curved mixing layer

5 Closure

The imposition of longitudinal, destabilising, curvature on a two-dimensional turbulent mixing layer produces increases in the spreading rate and shear stress broadly in accord with expectations based on model studies but probably less than would be the case were the equivalent plane flow truly self-preserving in its turbulent properties. The plane flow has been examined in detail in view of the scarcity of published data which contain all components of the Reynolds stress tensor. We have found that, while the mean flow, $\overline{uv}$ and $\overline{u^2}$ become self-preserving quite quickly, high initial levels of $\overline{v^2}$ persist far downstream with significant consequences for the curved flow. In contrast to the results obtained by Wood and Bradshaw (1982) we do not find that the wall bounding the high velocity potential flow exerts any significant influence on the turbulence in the shear layer.

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