J. Fluid Mech. (1973), *vol.* 59, *part* 4, *pp.* 737–743
Printed in Great Britain

Flow through non-uniform gauze screens

By J. L. LIVESEY AND E. M. LAWS
Department of Mechanical Engineering, University of Salford

(Received 1 March 1973)

An experimental investigation into flow through shaped gauze screens in two-dimensional and axisymmetric situations has shown that there is disagreement between measured velocity profiles and those computed from the method developed by Elder (1958). This disagreement has been shown to be attributable to the retention of a term of second order in the basic linearization and comparisons between experimental and theoretical profiles omitting this term are in good agreement.

1. Introduction

Early empirical and *ad hoc* methods of profile generation, which in general required considerable experimental work, have been superseded by methods with a strong theoretical basis in which the required downstream velocity distribution is related to a resistance grading produced either from a variably spaced grid of parallel rods (Owen & Zienkiewicz 1957) or a shaped gauze screen (Elder 1958).

The method due to Owen & Zienkiewicz (1957) has been verified experimentally and used successfully to generate specified velocity distributions by several different workers (Livesey & Turner 1964; Cowdrey 1967). This method was shown by Elder (1958) to be a particular case of his own analysis.

The focus of the present investigation was the shaped gauze screen. This form of screen used as a velocity profile generator has obvious advantages in axisymmetric and three-dimensional flow situations. The ability to vary the gauze (say mesh and wire diameter) offers the possibility of varying both the turbulence intensity and scale, at least initially, in the downstream flow.

The initial aim of this investigation was to apply Elder's method (which was supported by experimental evidence: Elder (1958), Turner (1969)), in which the velocity profiles far upstream and far downstream of the screen, the screen shape and the gauze properties are linearly related, in order to generate arbitrary velocity distributions in two-dimensional, axisymmetric and, ultimately, three-dimensional flow. A supporting experimental investigation indicated that in certain circumstances the method gave obviously incorrect results. The authors were thus led to re-examine Elder's treatment of the equations governing flow through gauze screens.

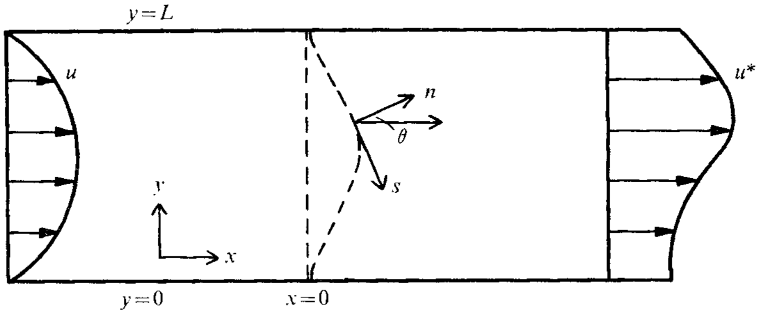

FIGURE 1. Two-dimensional co-ordinate systems.

2. The linearization due to Elder (1958)

The screen arrangement and co-ordinate system are shown in figure 1. Equation (1.8) in Elder (1958) gives the following conditions at the screen, based on the assumption that θ, the angle between the normal to the screen and the flow direction, is small:

$$u_1 = u_2 = q, \tag{1}$$

$$Bq \tan\theta = (1-B)\, v_1 - v_2, \tag{2}$$

$$\frac{\partial}{\partial y}(\gamma q^2) = 2q\left[\frac{du}{dy} - \frac{du^*}{dy}\right], \tag{3}$$

in which u and v are the non-dimensional velocity components at the screen in the x and y directions, suffixes 1 and 2 denote values measured upstream and downstream of the screen respectively, q is the non-dimensional velocity component at the screen, u and u^* are the non-dimensional velocity distributions far upstream and downstream of the screen, B is the gauze deflexion coefficient defined by $Bv_{s1} = v_{s1} - v_{s2}$, suffixes n and s denote values measured normal and tangential to the screen, $\gamma = K\cos^2\theta$ and K is the gauze resistance coefficient defined by $K = \Delta p/\frac{1}{2}\rho U_n^2$, where Δp is the loss in static pressure through the gauze, ρ is the fluid density and U is the local velocity upstream of the screen.

The angle θ is assumed small and $0 \leqslant B \leqslant 1$; with the additional assumption that the variations in q are small, the product $Bq\tan\theta$ is approximated to $B\tan\theta$ in (2).

Elder approximated γ by the expression $\gamma_0(1+s(y))$, where γ_0 is a mean value and the assumption is that $|s(y)| \ll 1$, however, since $\gamma = K\cos^2\theta$, $s(y)$ is essentially a second-order term in θ. The nature of the s term can be understood more fully by writing

$$\gamma_0 = \int_0^1 K\cos^2\theta\, d(y/L) \quad \text{as} \quad K_\alpha \cos^2\alpha,$$

where α is a mean gauze angle. Thus

$$s(y) = \frac{K\cos^2\theta}{K_\alpha\cos^2\alpha} - 1 \simeq \frac{(k^2-k_\alpha^2)+\frac{1}{2}(k_\alpha^2\alpha^2 - k^2\theta^2)}{k_\alpha^2(1-\frac{1}{2}\alpha^2)},$$

where $k = \sqrt{K}$ and $k_\alpha = \sqrt{K_\alpha}$.

To first order the first term in the numerator on the right-hand side of this equation may be approximated to $2k_\alpha \delta k$, whilst the second term may be re-written as $\frac{1}{2}(k_\alpha \alpha - k\theta)(k_\alpha \alpha + k\theta)$, which may be approximated to second order as $\frac{1}{2}(\alpha^2 - \theta^2)k_\alpha^2$. Hence

$$s(y) \simeq \delta K/K_\alpha + (\alpha^2 - \theta^2). \tag{4}$$

Thus if the average screen angle is small and variations of the local gauze angle are small the second term in (4) is of second order but the first term is of first order. If θ is constant the second term is identically zero. If θ is not small the second term becomes of first order; however, the conditions under which (1)–(3) were obtained are then violated and the validity of the whole theory might be expected to be in doubt. Equation (1.10) in Elder (1958), i.e.

$$u - u^* = \gamma_0(q-1) + \tfrac{1}{2}\gamma_0 s(y), \tag{5}$$

is valid only for the cases $\theta \equiv 0$, $K = K(y)$ or θ constant and small. As Elder pointed out the first condition in (5) gives a generalized statement of the result of Owen & Zienkiewicz (1957).

When θ is variable the order analysis clearly indicates that the $s(y)$ term should be discarded and the equation reduced to

$$u - u^* = K(q-1). \tag{6}$$

Though this equation is strictly valid only for θ small the experimental evidence of this paper and of Livesey & Turner (1964) and Livesey & Laws (1972) shows surprisingly good agreement with the theory for relatively high shear parameters ($du^*/d(y/L)$ as high as 0·8) and relatively high θ's (θ as large as $\frac{1}{4}\pi$). In view of this agreement, it is possible that the extension to a higher order theory, say second order, if attempted, would produce terms which are basically self-cancelling and thus reduce to the first-order theory presented here. Thus to achieve an improved theory a third-order theory would be necessary.

3. Modification of theory

The modifications to the analysis of § 2 of Elder's (1958) paper reduce Elder's equation (2.12) to

$$u^* - 1 = A(u-1) + E\sum_{n=1}^{\infty} \alpha_n \cos(n\pi y/L), \tag{7}$$

where E and A are constants given by

$$E = K/(2+K-B) \quad \text{and} \quad A = 1 - K(1-E).$$

The Fourier coefficients α_n are related to the screen shape by the equation

$$B\tan\theta = \sum_{n=1}^{\infty} \alpha_n \sin(n\pi y/L). \tag{8}$$

The solutions of the two distinct problems which can be solved by this analysis, viz. (i) the calculation of the velocity distribution downstream of a shaped gauze screen, or (ii) the calculation of the screen shape required to produce a specified

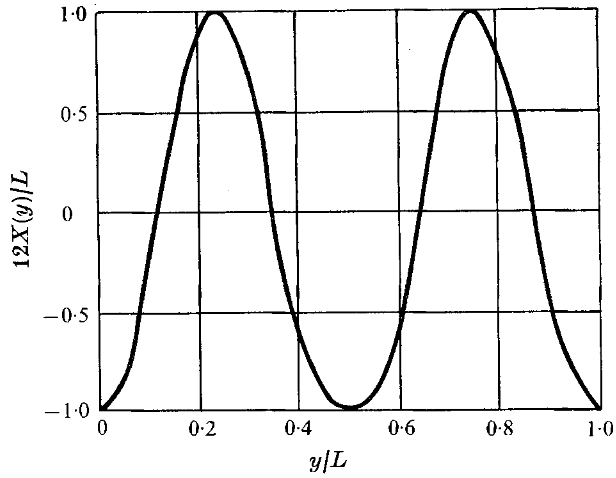

FIGURE 2. Two-dimensional screen shape.

downstream profile, may both now be easily obtained from (7) and (8). (If the $s(y)$ term is retained the solution of (2) requires an iterative technique (Turner 1969) in order to obtain what is now recognizable as a 'pseudo' solution.)

4. Experimental results

Experimental results were obtained for both two-dimensional and axisymmetric flow. Results for the latter case can be found in Livesey & Laws (1972), although several of these results are included here.

A simple demonstration of the effect of the inclusion of the $s(y)$ term is obtained from a test choosing the two-dimensional screen shape $X(y)$ given by

$$X(y)/L = -\tfrac{1}{12}\cos(4\pi y/L),$$

which is shown in figure 2.

Applying equations including the $s(y)$ term would give the downstream velocity distribution as

$$u^* - 1 = A(u-1) - \tfrac{1}{2}(1-A)\,s(y) + \tfrac{1}{3}\pi EB\cos(4\pi y/L), \qquad (9)$$

where

$$s(y) = K/\gamma_0(1 + c^2\sin^2(4\pi y/L)) - 1,$$

$$\gamma_0 = K\tan^{-1}[(\tfrac{1}{81}\pi^4 - 1)(1 + \tfrac{1}{9}\pi^2)]^{-1}, \quad c = \tfrac{1}{3}\pi EB$$

and E and A are given by

$$E = \gamma_0/(2 + \gamma_0 - B) \quad \text{and} \quad A = 1 - \gamma_0(1-E).$$

Neglecting the $s(y)$ term would give the downstream profile as

$$u^* - 1 = A(u-1) + \tfrac{1}{3}\pi EB\cos(4\pi y/L), \qquad (10)$$

where $E = K/(2 + K - B)$ and $A = 1 - K(1-E)$.

In figure 3 the experimental results are shown together with the theoretical results obtained from (9) and (10). The tunnel used had an 18 × 18 in. working

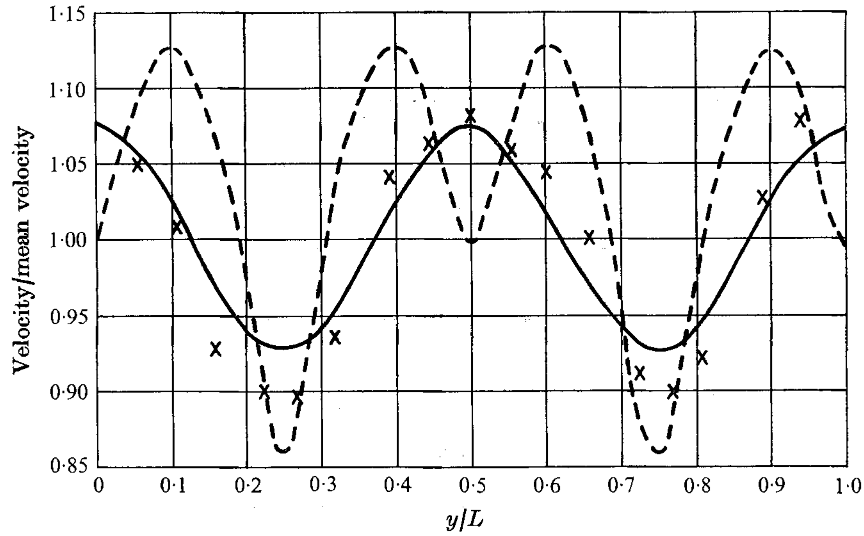

FIGURE 3. Comparison between theoretical and experimental profiles. ——, theoretical solution excluding the s term; – – –, theoretical solution including the s term; ×, experimental results.

section and the mean test velocity was 90 ft/s. The gauze used was 16-mesh, 27 s.w.g. with $K = 1{\cdot}05$ and $B = 0{\cdot}2$.

As can be seen from figure 3 the solution obtained from (9) is not in agreement with the measured profile (measured $\frac{1}{4}L$ downstream of the screen) whilst the profile obtained from (10) is in reasonable agreement.

In addition a theoretical and experimental investigation was conducted for the axisymmetric case. Figures 4 (*a*) and (*b*) show some results from this investigation. The screen used was basically quartic in shape and had a polar height of 0·75 in. (the pipe diameter being $2r_2 = 4{\cdot}06$ in.). The gauze was 16-mesh 27 s.w.g. In these figures the solid lines are the theoretical results ignoring the s term whilst the dotted lines are the theoretical results including the s term. The experimental results were obtained from a traverse one diameter downstream of the screen. Though in figure 4 (*a*) the two solutions (including and omitting the s term) are similar and both are in reasonable agreement with experiment, clearly in figure 4 (*b*) the solution including the s term is in error whilst the solution neglecting the s term is in agreement with the experiment.

The experimental results obtained by Elder (1958) and Turner (1969) however were in apparent agreement with the theory including the $s(y)$ term. In Elder's case the results were obtained for flow downstream of an inclined screen and a parabolic screen. In the first case the $s(y)$ term is identically zero since θ is constant. In the second case though θ is variable the screen was positioned so that its pole faced downstream and for this case the solutions including and excluding the $s(y)$ term are similar. Thus for both of these cases the apparent agreement between Elder's theory and experiment is coincidental. The screens tested by Turner (1969) were such that $|s(y)|$ was small and thus the effect of the term's inclusion was not distinguishable from experimental scatter.

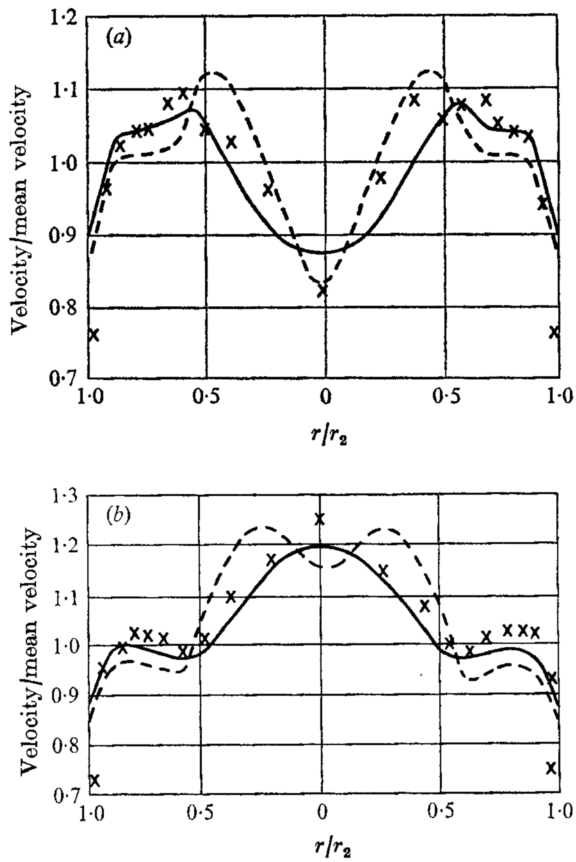

FIGURE 4. Comparison of results with pole of screen facing (*a*) downstream and (*b*) upstream. ——, theoretical solution excluding the *s* term; – – –, theoretical solution including the *s* term; ×, experimental results.

5. Conclusions

The analysis developed by Elder (1958) (equation (5)) has been shown to be applicable only for the case of flow through a screen of constant θ and constant or varying resistance. When the screen angle varies across the duct it has been clearly demonstrated by experiment that (5) is in error. The discrepancy between theory and experiment in this case has been shown to be attributable to the inclusion of a second-order term in the essentially first-order theory. For the variable-θ situation, equation (6) is valid. With this modification the analysis gives a useful relationship between a non-uniform screen shape and the velocity distributions far upstream and far downstream of the screen. It should be emphasized, however, that the theoretical limit on the analysis is that θ is small and thus care should be taken not to misuse the analysis.

The authors acknowledge the helpful advice of Dr H. K. Zienkiewicz, University of Exeter, especially in relation to the demonstration of the linearization.

REFERENCES

Cowdrey, C. F. 1967 A simple method for the design of wind tunnel velocity profile grids. *N.P.L. Aero Note*, no. 1055.

Elder, J. W. 1958 Steady flow through non-uniform gauzes of arbitrary shape. *J. Fluid Mech.* **5**, 355.

Livesey, J. L. & Laws, E. M. 1972 The simulation of internal flow velocity profiles by means of shaped wire gauze screens. *A.I.A.A. Paper*, no. 72–1965.

Livesey, J. L. & Turner, J. T. 1964 The generation of symmetrical duct velocity profiles of high uniform shear. *J. Fluid Mech.* **20**, 201.

Owen, P. R. & Zienkiewicz, H. K. 1957 The production of uniform shear flow in a wind tunnel. *J. Fluid Mech.* **2**, 521.

Turner, J. T. 1969 A computational method for the flow through non-uniform gauzes: the two-dimensional case. *J. Fluid Mech.* **36**, 367.