Figs 2 and 3 show clearly that the thermal conductivity of the uranin has a constant value up to an average test block temperature of about 55 °C after which it is seen to decrease. At the higher average temperatures, the heated surface temperature was as much as 90 °C and the test blocks were beginning to soften. The apparent temperature dependency of the thermal conductivity at higher temperature is, therefore, more likely to be the result of a change in the structure of the material. For the temperature range in which the uranin can be sensibly used as a solid material, the thermal conductivity has a constant value of about 0.43 W/mK.

The errors involved in the experiment were estimated to be of the order of 2%. These were mainly due to voltage fluctuations from the thermocouples and a slight variation in the thickness of the test blocks after solidification. The scatter in the results of Fig 3 reflect this error. A least squares regression analysis in the linear portion of Fig 2 would give a single value for the corresponding section of Fig 3. The individual data points and their scatter were retained and plotted in Fig 3, however, as a demonstration of the experimental consistency.

Conclusions

To complement a long term research programme involving experimental and theoretical aerosol techniques, it has been necessary to find the thermal conductivity of uranin (fluorecein sodium). Two solid uranin test blocks were manufactured by allowing a strong water/uranin solution to dry out and solidify. The blocks were exposed to one-dimensional steady-state conduction by heating one surface using electrically heated copper elements. The experimental method was found to be very satisfactory and produced a constant value for the thermal conductivity of uranin of 0.43 W/mK.

Acknowledgements

The authors wish to acknowledge the assistance and suggestions received from Drs D. J. Ryley and H. Barrow.

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CONFERENCE REPORT

12–14 September 1983, University of Karlsruhe, FRG

Fourth Symposium on Turbulent Shear Flows

Evidence of the increasing interest in shear flows was found at this, the fourth in a series of biennial symposia, in the large number of papers (nearly 100) spread over 18 sessions, 12 of which were held in parallel pairs. In addition there were two Open Forum sessions at which workers were able to talk briefly about current research. The papers were selected from 190 extended abstracts, and of those selected, it is intended that about 30 will be published formally by Springer-Verlag, following the practice with the previous symposia. Doubtless a number of the other papers will appear in journals or other publications. The symposium was well attended, attracting some 250 participants.

In a short report it is clearly impossible to give adequate coverage of all the topics discussed at the symposium. Thus the report is written from the point of view of one on the edge of the subject and more interested in its engineering implications than concerned with fundamental aspects of turbulent shear flows. The papers mentioned below are grouped somewhat arbitrarily, and in some cases cutting across the grouping of the symposium sessions.

Internal and external boundary layer flows

In this traditional area which has received attention for many decades, there were some interesting ideas and developments. Two papers on compressible flow were presented. Vandrome *et al*[2] presented a new calculation method for internal boundary layers including shock waves, and Muck and Smits[5] studied the boundary layer/shock interaction at a 16° corner, presenting details of the turbulence quantities.

Perry *et al*[1] studied the flow over a regular rough surface comparing shear stress values with those for a smooth surface. Andreopoulos *et al*[3] studied the details of flow close to the wall in a large wind tunnel using a hot wire temperature wake sensor.

Three papers studied the effects of rotation on boundary layers, and so would have application to rotating fluid machinery. Witt *et al*[8] made measurements in a rotating wind tunnel, studying the turbulence details and comparing with non-rotating results. Pouagare and Lakshminarayana[14] produced a calculation method for rotating flows using a modified k-ε model* and compared their results with experiments on a rotating cylinder and in a rotating duct. Kim[13] simulated rotating channel flow using large eddy simulation, again comparing results with experiments.

Shizawa and Honami[16] studied the effects of concave curvature on a zero pressure gradient boundary layer, and showed some interesting effects at the discontinuity in curvature when going from a flat to a curved surface. Patel *et al*[7] considered the calculation of three-dimensional boundary layers on ship hulls, where the special features of high curvatures, strong viscid–inviscid interaction and surface waves produce some interesting problems.

Three-dimensional and curved flows

Three papers included 'secondary flow' effects. Nakagawa *et al*[6] studied the turbulence driven secondary flows which give rise to sediment ridges in wide straight rivers. Chang *et al*[11] calculated the flow and heat transfer in a 180° rectangular bend using both standard and modified k-ε models. Rojas *et al*[15] presented laser velocimeter measurements in C-shaped and S-shaped rectangular diffusers, showing the strong secondary flows and the effects on turbulence levels.

Hartmann[12] studied a highly curved wall jet and showed how a spoiler could increase the angle of attachment of the jet by relaminarising the boundary layer downstream of the start of the jet.

Heat transfer

Erikson *et al*[4] studied a highly cooled boundary layer, work with application to cooled gas turbine blades. They measured mean velocity and turbulence quantities and compared the results with calculations using a modified k-ε model of turbulence. Iritani *et al*[27] studied the turbulence structure and heat transfer close to the wall, and showed how the 'streaky' or elongated turbulence structure in the viscous wall region produced a similar turbulent temperature field. A further study of boundary layer flow, but this time due to natural convection, was made by Cheesewright and Dastbaz[26]. They found that close to the wall a streaky structure existed, similar to that for forced flow, but further out the structure differed considerably from that for forced flow.

Among the other papers in this section, two from Cornell studied thermal line sources in grid turbulence[25,28].

Free turbulence

Quinn *et al*[19] studied a jet issuing from a sharp edged rectangular slot of aspect ratio 10. They found interesting off-centre peaks of velocity and produced evidence of negative production of turbulence kinetic energy near the peaks. Chandrasekhara and Ramaprian[18] took measurements in asymptotic jets and buoyant plumes, showing the effect of buoyancy on the turbulent structure.

Among the papers on wakes, Tsiolakis *et al*[10] studied the interaction of the wake from a cylinder and a flat plate turbulent boundary layer. The cylinder had its axis perpendicular to the flow and parallel to the flat plate and was immersed in the boundary layer. A similar topic was investigated by Takeuchi and Okamoto[9] who measured the effect of the wind tunnel walls on a wake in a plane parallel to the walls. The wake width was reduced, the turbulence increased, and the drag on the bluff body producing the wake was also increased.

The papers on mixing layers were fairly fundamental; for example, Sherikar and Chevray[20] studied a plane mixing layer using an interesting technique whereby flow visualisation pictures were synchronised with laser velocity measurements. In the geophysical flows session Jirka[21] presented a paper on an entrainment model for a horizontal buoyant jet with application to situations such as the flow of a warm river into a cold sea.

Recirculating flows

There were a number of papers on confined jets. Binder and Kian[17] studied experimentally a jet in a diverging duct and found the effect of only 2.5° divergence to be considerable, especially when recirculation was present. Suzuki *et al*[32] measured turbulence quantities in the recirculating region and related them to the high heat transfer observed there. Johnson and Bennett[30] investigated experimentally the mixing downstream of two co-axial jets discharging into a suddenly expanded circular duct. Their aim was to improve turbulent transport models. Hallett and Günther[29] took measurements in swirling flow downstream of a sudden expansion, where vortex breakdown and vortex precessing give two distinct types of flow.

A number of other papers were presented covering such topics as flow over steps and around bluff bodies. One interesting paper with some fine flow visualisation was by Ruderich and Fernholz[31] who studied the flow behind a normal flat plate spanning, a wind tunnel, with a splitter plate downstream on the axis of symmetry. Pulsed-wire anemometry was also used to improve understanding of the complex vortex and recirculation patterns.

Experimental techniques

A number of papers already mentioned contained interesting points on experimental techniques. For instance Perry *et al*[1] used a 'flying' hot wire on an air bearing sled in conjunction with studying the effect of 'wedge angle' of the velocity vector on crossed wires. Witt *et al*[8] commented on the use of linearisers for hot wires, advocating the use of analogue signal processing rather than the popular trend towards digital processing. Many authors referred to the use of laser anemometry, both laser doppler and dual focus systems. There were also a number of interesting flow visualisation techniques, such as the paper already mentioned by Sherikar and Chevray[20] and Ruderich and Fernholz[31].

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* k—turbulent-kinetic energy; ε—its rate of dissipation

Pulsed wire anemometry was also used by many authors, particularly for recirculating flows, because of its cheapness and ease of use compared with laser anemometry. In the session on experimental techniques, Dengel and Vagt[23] compared the use of hot wires and pulsed wires for measurements in a free jet and a boundary layer. They produced histograms to indicate the number of back flow events and considered the corrections required for hot wires in such flows.

There were two papers on the measurement of wall friction. Nitsche *et al*[24] described a method using two Preston tubes of different sizes which enabled skin friction to be evaluated in flows where uncertainty existed about the similarity law of the wall. Acharya and Escudier[22] described a floating element device which measured directly the shear force on the wall.

General comments

It seemed clear that the k-ε eddy viscosity model for turbulence is regarded as 'standard', and many papers either used it or were concerned with improvements or modifications. There was, however, some mention of other models, including progress in direct Reynolds stress modelling. There also seemed a trend towards the use of 'finite volume' numerical techniques as opposed to the older finite difference methods. On a more fundamental level there were a number of papers concerned with eddy simulation and the prediction of frequency spectra. These methods require large computing times (one author mentioned 600 h) and are of restricted application. It seems unlikely that, in the near future, they will be of use in engineering applications although they may hold the secret to the long term development of calculation methods. Experimental work of a fundamental nature was presented by several authors.

Although not reported here it should be mentioned that there were sessions on coherent structures, reacting flows, two phase flows, and numerical schemes and computations. The Open Forum sessions were interesting but somewhat frustrating due to the necessity of very short presentations. Of particular note was some spectacular film, from W. C. Reynolds of Stanford University, of bifurcating and 'blooming' jets, the latter referring to a jet spreading at about 45° to its axis. These effects were produced by longitudinal and in plane oscillation of the jet nozzle, tuned to the vortex shedding frequency.

At the conclusion of such a symposium one feels slightly dazed at the range and volume of work going on in this field. However, the organisers should be congratulated on the generally smooth running of the sessions and for providing the opportunity for the expert and novice alike to review the subject, share experiences and to appraise their own research objectives.

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Authors and the paper titles are listed alphabetically under the headings of the symposium sessions. The location of the work is indicated although in one or two cases this was not clear; * indicates the author corresponding to that location when authors have different addresses.

Internal boundary layers

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External 2-D boundary layers

3. ***Andreopoulos J., Durst F and Jovanovic J.** On The Structure of Turbulent Boundary Layers at Different Reynolds Numbers. *Universitat Karlsruhe, FRG*
4. **Eriksen S., Wittig S. and Rud K. P.** Optical Measurements of the Transport Properties in a Highly Cooled Turbulent Boundary Layer at Low Reynolds Number. *Universitat Karlsruhe, FRG*
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3-D flows

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7. **Patel V. C., Sarada O. P. and Shahshahan A.** Calculation of Ship Boundary Layers. *University of Iowa, USA*
8. **Witt H. T., Watmuff J. H. and Joubert P. N.** Some Effects of Rotation on Turbulent Boundary Layers. *University of Melbourne, Australia*

Wakes

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Curved flows

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Jets

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Free Shear and periodic flows

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Geophysical flows

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Experimental techniques

22. **Acharya M. and Escudier M. P.** Measurements of Wall Shear Stress in Boundary Layer Flows. *Brown-Boveri Research Centre, Baden, Switzerland*

23. **Dengel F. and Vagt J. D.** A Comparison Between Hot-Wire and Pulsed-Wire Measurements in Turbulent Flows. *Technische Universitat, Berlin, FRG*

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Heat transfer

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26. **Cheesewright R. and Dastbaz A.** The Structure of Turbulence in a Natural Convection Boundary Layer. *Queen Mary College, London, UK*

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Recirculating flows

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32. **Suzuki K., Ida S. and Sato T.** Turbulence Measurements Related to Heat Transfer in an Axisymmetric Confined Jet with Laser Doppler Anemometer. *Kyoto University, Japan*

20–22 September, 1983, Budapest, Hungary

FLOMEKO'83

FLOMEKO'83 was the third flow measurement conference to be sponsored by the Technical Committee No. TC9 of IMEKO (the International Measurement Konfederation). This Technical Committee was created after the London Congress of IMEKO since it had been found that Congress sessions devoted to flow measurement were increasingly stimulating and well-attended.

I was invited to be Chairman and believed that a succession of conferences specifically on flow measurement held in different parts of the world would provide opportunities for participation to many who would otherwise have no chance of attending. The first FLOMEKO was held at Groningen in The Netherlands in 1978 and the second in Tokyo at the end of 1979. As a co-sponsor the IMEKO Technical Committee was then involved in 1981 in the Instrument Society of America Conference at St Louis so maintaining this movement around continents.

FLOMEKO'83, held in Budapest on 21–23 September 1983 was another successful event, this time with 100 delegates from 20 countries, thus maintaining a strong international flavour. It had been hoped that more delegates from the Eastern European countries would have come on this occasion, although Hungary itself was well represented.

One of the noteworthy aspects of these conferences has been the use of the English language. It was remarkable and most laudable to find, in Budapest, so many delegates willing and able to make presentations and take part in discussions in English.

With just 30 papers on a range of topics which covered both the conventional and the novel flowmeters in use around the world there had to be gaps. For once there were no 'straightforward' papers dealing with the problem of coefficients of pressure difference devices: instead the session on these devices had some unusual papers, for instance two from Poland dealt with the use of an orifice Wheatstone bridge arrangement for measuring the fuel flow to internal combustion engines.

Two papers which attracted significant interest and comment were from the UK and Japan. That from the UK dealt with the development of a four-path ultrasonic flowmeter for the measurement of large flows of natural gas which has had field trials on British Gas Corporation pipelines. Professor Yamasaki presented the paper on a novel electromagnetic flowmeter.

The conference started, however, with several sessions on transfer standards and calibration facilities and the importance of a reliable, accurate and traceable network of measurement factilities was again emphasised. Of the nine papers in these sessions the two, in my opinion, which were of significance to the whole pattern of measurement were presented by Dr W. C. Pursley, from the National Engineering Laboratory in the UK, and by Dr J. Gyory from the Hungarian Company, Vegyepszer. Dr W. C. Pursley described an exercise in which the volumetric standards of six standards laboratories in five countries were compared using a transfer package incorporating two positive displacement meters. This twin-meter package concept has been developed at NEL from a technique