FILM REVIEWS

The work of the U.S. National Committee for Fluid Mechanics Films is now well known. With financial support from the National Science Foundation, and with facilities provided by Educational Services Incorporated, the Committee have prepared about fourteen 30 min sound films and about fifty shorter silent loops, and many more are in production. Films on fluid mechanics have been made before now by other people, but the scale of this programme, the quality of the Committee's work, and the wide distribution of the products make these films a notable development in the academic world. Already the impact on the teaching of fluid mechanics in colleges and universities has been considerable, and it is likely that films are here to stay as a regular teaching aid. Fluid mechanics *is* a photogenic subject; and the Committee have opened our eyes to what can be done by an effective combination of thought and money.

The *Journal of Fluid Mechanics* will publish reviews of films in future, and we begin with a batch of five films made by the N.C.F.M.F., three of them being new releases. The art of reviewing scientific films is even newer than the art of making them, and it remains to be seen how useful reviews can be. A review can at least serve as a vehicle for constructive criticism, and the work of the N.C.F.M.F. now has such importance than an effort should be made to provide that criticism.

All the N.C.F.M.F. films are available for purchase or rental from Encyclopaedia Britannica Films, 1150 Wilmette Avenue, Wilmette, Illinois. They may also be borrowed or rented from the following agencies in other countries.

Australia: National Library, Film Division, 113 London Circuit, Canberra, A.C.T.

Canada: Canadian Film Institute, 1762 Carling, Ottawa 13, Ontario.

France: Office National des Universités et Ecoles Françaises, Service du Film de Recherche Scientifique, 96 Boulevard Raspail, Paris 6.

U.K.: Central Film Library, Government Building, Bromyard Avenue, Acton, London, W. 3.

Boundary Layer Control. By C. D. Hazen. 16 mm, sound, black and white, 25 min. $95.00.

This film opens with some elegant smoke-tunnel pictures showing the flow past an aerofoil at various angles of attack. Transition and separation are thereby identified. The first half of the film is then devoted to transition control as a means of reducing the drag of streamlined bodies. The beneficial effect of a negative pressure gradient is demonstrated by comparing the flow past two aerofoils, one with maximum thickness farther back than the other. The point is made at a leisurely pace with additional shots showing how the surface pressure distribution on a multitube manometer changes with angle of attack in each case. The manometer is also used to compare the total pressure in the wake as measured by a rake of Pitot tubes, and the narrowing of the wake, associated with an extended laminar boundary layer, is clearly shown. The same techniques are used to show the beneficial effect of distributed suction. In explanation of this effect reference might have been made to the important action of suction in tending to suppress the inflexion point in the velocity profile for a region of rising pressure. In this half there is also some mention of the effects of roughness and noise, but there is no mention of the destabilizing effects of surface waviness and sweepback. On wings with leading-edge sweepback exceeding about 20 degrees transition occurs close to the leading edge: smoothing the surface and reducing external disturbances have negligible effect in this case. It is therefore misleading to imply that the engines of a swept-wing aircraft like the DC8 are mounted on pods beneath the wing in order to reduce the disturbing effect of noise and vibration; and to imply that the wings are made smooth in order to delay transition, for the aim is of course to reduce turbulent skin friction.

The second half on separation control begins with some smoke-tunnel pictures showing the second use of suction: as a means of preventing breakaway. This is followed by the use of a nose flap for eliminating leading-edge separation and is again an excellent demonstration. After a passing reference to vortex generators, the action of leading-edge slats and slotted flaps is shown in the smoke tunnel. Here unfortunately the action of slats is not explained precisely in terms of the reduction of adverse pressure gradient near the nose. The smoke-tunnel pictures are also unconvincing due in part to separation off the side walls of the tunnel. The film then ventures into blowing and finally circulation control, with some convincing shots showing jet-flap effect.

This film is not a complete discussion of boundary-layer control bearing in mind all its potential and actual applications. It omits any mention of the effects of heat transfer on transition, or of moving surfaces as a means of separation control. There is no mention of transition by separation and subsequent reattachment, or of the effects of roughness and additives on turbulent skin friction. There is also no mention of shock-induced separation even though vortex generators are cited. Bluff bodies as such are not discussed and the student might well conclude from the discussion on transition that roughness will always increase the drag of a body. He may therefore be puzzled by the well-known example of a golf ball, which, at appropriate Reynolds numbers, has significantly more drag if it is made smooth. Clearly a longer film would be required to touch on all these topics and to be fair the main purpose of this film is to introduce undergraduates to aeronautical applications, to present the ideas and to stimulate interest. In the latter connexion it might have been worth while to include shots of the Northrop X21A as an example of a recent experimental aircraft with laminarized wings, and of the Blackburn NA39 as an example of a successful application of the use of blowing to reduce landing and take-off speeds.

This is a film that one might show once to undergraduates in aeronautical engineering. Most institutions will probably project it no more than once a year, and they may therefore find it satisfactory to borrow a copy from a library as the need arises.

B. G. NEWMAN

Rheological Behaviour of Fluids. By H. MARKOVITZ. 16 mm, sound, black and white, 22 min. $85.

This film provides an admirable introduction to the behaviour of fluids which do not have the linear viscous properties usually designated as Newtonian. Vivid demonstrations are given of the non-linear and elastic (or memory) properties of solutions of long-chain molecules. As examples, the short-term elasticity and long-term fluidity of bouncing putty are shown; the elastic recoil of immense proportions shown by an elastic fluid in Couette flow, or when being poured from a beaker, is contrasted with the total absence of such recoil in a Newtonian fluid like glycerine or honey; pseudo-plastic and dilatant behaviour in pipe-flow are shown, both in terms of output as a function of pressure gradient and in terms of velocity profile; the high yield stresses characteristic of clay suspensions are visibly demonstrated.

All the experiments are done clearly and simply with good visual presentation of the results. They are mostly qualitative rather than quantitative. The treatment is phenomenological, in terms of continuum mechanics: no attempt is made to explain the behaviour exhibited.

The only regret I had was when the film ended: it had by no means exhausted the interest of the audience, who might well have been shown some of the more complex flow effects that can arise, such as 'elastic turbulence' in polymer melts, which present such a challenge to those seeking to interpret fluid mechanics effects in general.

J. R. A. PEARSON

Magnetohydrodynamics. By J. ARTHUR SHERCLIFF. 16 mm, sound, black and white. 26 min. $105.00.

This welcome addition to the series shows seven main sequences which illustrate the following effects.

(i) *The deflexion of a mercury jet by a* $\mathbf{j} \wedge \mathbf{B}$ *force*

The current $\mathbf{j}$ flows along the jet, which falls under gravity, and the field $\mathbf{B}$ is perpendicular to the jet. The jet is deflected visibly when the current is switched on.

(ii) *The creation of vorticity by the application of rotational* $\mathbf{j} \wedge \mathbf{B}$ *forces*

The experiment here is conducted in an electrolyte in a shallow dish. The geometry of the experiment is such that curl $(\mathbf{j} \wedge \mathbf{B}) = (\mathbf{j} \cdot \nabla)\mathbf{B}$. The current is first caused to flow in a region of uniform $\mathbf{B}$, and the effect is merely to change the pressure distribution. The current is then caused to flow in a region of non-uniform $\mathbf{B}$ and the generation of vorticity is made visible by means of a sprinkling of powder on the surface. The electrolyte is then caused to flow through the region of vorticity production, and the rotationality of the velocity profile downstream of this region is indicated using injected dye.

(iii) *The suppression of vorticity perpendicular to an applied field*

A small body is towed through a shallow dish of mercury across which a horizontal magnetic field can be applied. The irregular pattern of vertical vorticity is made 'visible' by reflecting a pattern of lines off the free surface. The vortices have a much shorter lifetime when the field is on than when it is off.

(iv) *Hartmann flow between concentric cylinders*

The inner cylinder is rotated and a strong radial field is applied. The theory underlying the experiment has been described by Heiser & Shercliff (*J. Fluid Mech.* **22**, 1965, 701). The radial field redistributes the vorticity to give a rigid body rotation in an annular core, and a Hartmann layer on each cylinder.

(v) *The elastic nature of the Lorentz force when* $R_m \gg 1$

This is the first 'large magnetic Reynolds number' effect to be mentioned. The difficulties of illustrating such effects under laboratory conditions are well known, and the problems of filming them in any convincing manner are almost insuperable. The effects are illustrated first by resort to an ingenious electrical feedback system that is capable of simulating the essential property of a perfectly conducting fluid, that magnetic flux through a material circuit is conserved. The feedback is linked to a coil which is free to rotate about a diameter in the presence of a magnetic field in the plane of the loop. Without feedback the motion is damped aperiodically; with feedback, the coil oscillates, indicating the elastic nature of the Lorentz force under these conditions.

(vi) *Simulation of Alfvén waves*

The immediate implication of the elastic nature of the Lorentz force, viz. the possibility of propagation of transverse waves along the lines of force of the field, is now demonstrated by placing five circuits, each with feedback and free to rotate as in (v), in line in a magnetic field. When the first circuit is moved, the motion is transmitted successively to the rest, and the impression (though not a very convincing one) is that a wave propagates along the line.

(vii) *Propagation of Alfvén waves in a real fluid*

The liquid used for this demonstration, a sodium–potassium alloy, is enclosed in a cylinder with a central current-carrying rod. A pulsed radial e.m.f. is applied causing a radial current to flow at the lower boundary of the fluid. The Alfvén mechanism causes a radial current sheet to propagate through the fluid in the axial direction. A search coil immersed in the fluid detects the passage of the wave and records a corresponding pulse on an oscilloscope. The over-all effect is somewhat weak and anticlimatic, but it might be exceedingly hard to do better; the difficulties are comparable with those that might be experienced if one foolishly tried to demonstrate high Reynolds number effects (and film them) using pitch as the working fluid.

The film ends (as it started) with a nice moving shot of a solar flare, and the comment that 'things get much more difficult when compressibility and other effects are important'. The material of the film is concentrated and far from elementary, and I suspect that I am not alone in finding that a single viewing was somewhat unsatisfactory. It is the sort of film that improves on a second viewing and improves still more on a third. On the first viewing, one gets a rather fleeting glimpse of a fascinating range of phenomena; on the second viewing, one arrives at a clearer understanding of the geometry and external conditions applied to the various experiments; and, on the third viewing, one can really come to grips with the actual behaviour of the fluid itself. I showed the film on two occasions to a class that had attended a course of 24 lectures on M.H.D., and it was clear from the discussion after the second viewing that even then certain sequences, notably (ii), (iv) and (vii) above, had been at best only partially comprehended. Part of the difficulty was undoubtedly due to the theoretical bias of the class, and to their lack of familiarity with the experimental techniques that were used. Perhaps a salutary side-effect of the film will be that it will bring theoreticians, such as these, face to face with some of the difficulties that experimentalists in M.H.D. experience.

It may not always be possible or practicable however to show a film such as this more than once to a given group of students. I suspect that the impact of the film might then be disappointing, unless the class were well prepared in advance, either by having the theory underlying each experiment explained, or perhaps by being asked to work out the theory for themselves in the form of set examples. In the absence of such preparation, the film would certainly convey the main message—that magnetic fields can strongly affect fluid motions —but possibly little else.

It is to be hoped that the various sequences of the film will soon be made available in the form of separate film loops similar to those that are already available from the earlier films in the series. I feel myself that the film will be most useful in this dissected form. A film illustration of an individual topic can have a dramatic and lasting impact. But there is a danger that the sudden switching from one topic to another within a single film may merely induce confusion in the uninitiated.

H. K. MOFFATT

Low Reynolds Number Flow. By Sir GEOFFREY TAYLOR. 16 mm, sound, colour. 33 min. $250.00.

This delightful film describes cases of fluid motion in which viscous forces are dominant. Less relevantly, but more importantly for fluid dynamics in the long run, it shows G. I. Taylor and something of his work. It was a brilliant idea to use one of these films as a vehicle for what is in part a documentary of the methods of a great man of the subject, and the outcome is a film which will please both those who wish to know something of G. I. and those who wish to understand flow at low Reynolds number. Without doubt there is scope for improvement in the making of films like these, but meanwhile this is one of the best available. As might be expected, it makes its appeal largely through original and penetrating little demonstrations. It is a bit light on explanation, but a class of third-year students of applied mathematics to whom I showed it after a preparatory lecture appeared to find it illuminating.

The film opens with examples of natural flow systems in which viscous forces are dominant, wriggling bull spermatozoa being at one end of the size range (a sight previously confined to those few fluid dynamicists with access to microscopes and bulls) and a majestic glacier at the other (but *is* a glacier a viscous fluid?). The expository part begins with a description of the jet-like motion due to a column of liquid falling on to the free surface of a stationary body of the same liquid, at four different values of the Reynolds number. At $R \ll 1$ the falling column coils up in a blob on the surface, as in the case of honey falling into a jar, while at the other extreme, $R \gg 1$, the familiar turbulent jet forms. The two intermediate cases show incidentally a strikingly well-defined 'head' to the submerged jet, smooth and roughly spherical and reminiscent of a buoyant drop of immiscible fluid in laminar motion. Laminar flow in a circular tube is then introduced as an example of a flow with dominant viscous forces despite a non-small Reynolds number, and a rather feeble experiment is performed to show that the discharge for a given pressure difference varies as the fourth power of the radius of tube. (It is a general criticism of these films, I think, that they often spend time on what purports to be a demonstration of a quantitative relationship—pointers go twice as far when something is changed, or balls fall four times as fast, or eight times the weight is needed, etc. Students should of course be encouraged to have a proper respect for observation, but this is not observation: it is a contrived show which is made to work. In the experiment referred to, red liquid discharging from the end of two tubes under the same pressure difference is collected in two irregularly shaped jars for a certain time, and the volumes are stated to be in the ratio 16; there is then a close-up view of the larger jar to show that the level of the liquid is indeed at a mark labelled '16'. I do not think a university text-book would contain photographs of a pointer against a scale or the weights on a beam-balance. In a film, as in a book, the emphasis should surely be on describing the result and showing how it is a consequence of basic laws, rather than on pretending to obtain the result.)

Flow in tubes leads on to lubrication, a practical topic obviously to the demonstrator's liking. A sheet of paper is shown to glide readily on a smooth table whereas one with holes does not. Manometers connected to the layer of fluid between a rotating shaft and an eccentric housing demonstrate that the pressure is high on the upstream side of the narrowest part of the layer and low on the downstream side, and there is an interesting shot of cavitation bubbles produced on the downstream side in a layer of fluid of high viscosity. To illustrate the point further the demonstrator has (very characteristically) devised a little toy, a 'teetotem', consisting of three nearly parallel flat plates at the end of radial arms joined to an axle. When the toy sits on a table, there is a wedge-shaped layer of air between each plate and the table, so that if the axle is spun between the fingers in one direction the toy 'floats' and keeps spinning whereas if spun in the other direction it is quickly reduced to rest by solid friction.

The reversibility of flow at low Reynolds number is demonstrated effectively by means of patterns of dye in a liquid between concentric cylinders. The outer cylinder is rotated through a certain angle, and then back through the same angle, with restoration of the original dye pattern—and also of the position and orientation of an immersed rigid body, although not of a flexible piece of yarn which is unstable in compression and buckles.

Sedimentation and falling bodies is the next topic. The speeds of spheres of different size falling under gravity are compared, and the retarding effect of a nearly vertical wall is demonstrated. A cloud of fairly uniform particles in a box is shown to develop a well-defined top as it falls through air, because particles which happen to get left behind are free from the retarding effect of neighbours and fall faster; it should perhaps be mentioned here that the presence of the container is essential, and that the interaction of particles in a cloud surrounded by clear fluid will make the particles fall *faster*. A long circular cylinder is said to fall twice as fast through syrup when end-on as when broadside-on. The demonstrator adds cryptically that this result holds for any long body of revolution, and I expect that in many parts of the world people who have seen the film are still wondering how this unfamiliar result can be proved. Then, with a contrast which will be prized by those who value the documentary aspect of the film, he uses a set-square and two drawing-pins instead of calculus in a demonstration of the corollary that the maximum deviation from a vertical path occurs when the cylinder axis makes an angle of 35° with the horizontal.

These results for the force on an inclined cylinder lead to considerations of the way in which a body might propel itself through fluid at low Reynolds number. The familiar method of propelling a boat by oscillating the rudder is shown to be useless when viscous forces dominate, but a body which makes a wire helix rotate about its axis does make progress. The propulsion is due here to the existence of a difference between the direction of the motion of a portion of the helix and the direction of the force exerted on it by the fluid, but one needs to think about the geometry a little to see the point. Spermatozoa propel themselves in a similar way, although the flexible tail is here waved to and fro in a plane. Somewhat confusingly, snakes and eels also swim by sending waves down the length of their body. The drag on a long cylindrical body varies with the direction of motion at high Reynolds number as well as at low Reynolds number, and the body with a rotating helical tail could swim also at high Reynolds number; the difference lies in quantitative considerations. This part of the film provides a fascinating glimpse at an unfamiliar corner of fluid dynamics.

The last demonstration is of the streamlines in a Hele Shaw cell, with an 'obstacle' discharging fluid into the space between the plates. It is useful to be able to see so clearly the streamlines in irrotational flow past a semi-infinite body, although the pedagogical value in the present context of flow with negligible inertia forces is perhaps doubtful.

The colour photography is superb throughout, the demonstrations are ingenious, and the script is beautifully lucid and concise. The film as a whole will give a great deal of pleasure and profit to young and old alike. It may not be quite what a systematic teacher would do, but there are plenty of other people who can do *that*. This whets the appetite for more. Could we have G.I. on other subjects, for instance rotating fluids, or electrohydrodynamics?

G. K. BATCHELOR

Channel Flow of a Compressible Fluid. By DONALD COLES. 16 mm, sound, black and white, 29 min. $110.00.

The steady one-dimensional flow of a compressible gas is now normally treated in the last year of an undergraduate or the first year of a post-graduate course in fluid mechanics. There is therefore a demand for films which would supplement the regular teaching in such a course at a level appropriate to the growing comprehension and experience of its students. Donald Coles's excellent film meets part of this need by giving a useful and thorough presentation of the effect of 'area change' in one-dimensional compressible flow. The approach (and nomenclature) is essentially that of chapters 4 and 5 of A. H. Shapiro's *The Dynamics and Thermodynamics of Compressible Fluid Flow*, vol. I (Ronald Press, 1953).

The film starts with a view of the convergent–divergent nozzle of a large wind tunnel, but most of the action takes place in a smaller two-dimensional channel with a flat bottom wall and an upper wall shaped to give the required area change. Static pressure taps along the channel are connected to a manometer board. The field of view includes the channel and the manometers. Air is sucked from the room through the channel and the back pressure is controlled by a manually operated valve at the outlet. The first sequence shows the variation of pressure distribution through a convergent–divergent channel as the back pressure is lowered. A change in noise is heard as the pressure distribution changes from a symmetrical subsonic pattern to an asymmetrical supersonic one. Schlieren techniques are then used to show the development of a shock downstream of the throat. There is a slight boiling motion which is accounted for by turbulence in the air surrounding the channel, but no explanation is given for a much more noticeable dark region near the flat wall downstream of the throat.The presence of a region of supersonic flow having been made clear from both the pressure distribution and the visual evidence of shocks the phenomenon of choking is then described. The economical presentation of the theory which then follows assumes some previous familiarity with the equations of motion and continuity in their differential form.

Strips of tape are placed on the flat bottom wall to produce a regular pattern of Mach waves, and with this aid the flow is examined again. In close-up the shock is shown to be a confused rather than an abrupt discontinuity. We are told that the noise is picked up by a microphone at the entry to the channel—an important admission, since only when heard from this vantage point does supersonic flow seem less noisy than subsonic flow! In one sequence in which the Schlieren knife edges are arranged to show gradients of density in the direction of the flow the high standards of exposition seem to be momentarily lowered and the point is lost. More emphasis is given to this second exposition of choking flow through a throat by some shots of a converging channel with a sudden enlargement after the throat. The expansion fan at the sharp corner is neatly delineated and the opportunity is taken to show the pattern of expansion waves and shocks in jets of various kinds including rocket exhausts.

The next topic, supersonic diffusion, is then introduced by establishing the need for efficient diffusion in aircraft engine inlets. A rather inadequately described picture of a thin normal shock in a large wind tunnel forms a background to a statement about the losses in shocks and the desirability of shock-free diffusion. The original channel and manometer board arrangement is then shown with a fixed convergent–divergent nozzle followed by a wind tunnel test section and a second convergent–divergent section whose throat area can be varied during operation. A series of experiments are then performed with various ratios of the second throat to the first throat area. When this ratio is only slightly greater than unity a trapped shock appears downstream of the first throat and the channel is blocked. The swallowing of the shock and starting of the channel is demonstrated. These experiments show very prettily that a shock is not stable in a converging channel. There is a good deal of repetition which may be criticized by those already familiar with the phenomenon. On the other hand, watching both the manometer board and the flow pattern is difficult and many less expert viewers will find the repetition helpful. In fact in this section the use of arrows, which were available in the first part of the film, would have added to the clarity.

There are some shots of an adjustable inlet on an aircraft as well as some good views of the XB 70. The film ends with simultaneous views of three channels showing choking, blocking and starting.

The standard of this film is as high as any produced by the U.S. National Committee for Fluid Mechanics Films. It should be shown at least twice during any normal course on one-dimensional gas dynamics. It puts not unrealistic demands on the instructor to ensure that all the many points are adequately understood, but this is as it should be. After showing the film to a group of staff and students, there were a number of minor criticisms, most of which I have mentioned. It was unanimously decided that it should be part of the departmental film library.

W. R. Hawthorne