*1965 Supplement*

*to*

# Fourth Decade of Hydraulics

# at

# The University of Iowa

(Bulletin 40, *Studies in Engineering*,
edited by Lucien M. Brush, Jr. and
Lawrence R. Mack, 1960)

Published by the

Institute of Hydraulic Research

The University of Iowa

Iowa City

# THESIS ABSTRACTS

**Decay of Turbulent Wakes Behind a Propeller.** GERT ARON. M.S. Thesis, February 1960; Professor Hubbard, adviser. Measurements were made of the axial components of mean velocity and turbulence intensity in the slipstream behind a propeller towed in an open channel. The experiments showed, in agreement with the theory, that the maximum mean velocity and turbulence intensity as well as the energy flux across a normal section of the slipstream varied inversely as the two-thirds power of the distance $x$ behind the propeller. The radius of the wake seemed to vary rather with the one-half than with the one-third power of $x$ predicted in the theoretical analysis. In order to obtain more reliable data, velocity and turbulence profiles should be measured farther downstream.

**Establishment of the Wake Behind a Disk.** THOMAS CARMODY. Ph.D. Dissertation, June 1963; Professor Rouse, adviser. An air-tunnel study of the establishment of the wake behind a disk at a Reynolds number of approximately $7 \times 10^4$ was undertaken. On the basis of the measured data, such a wake is fully established, that is, similarity profiles of the flow characteristics are formed, within 15 diameters of the disk, and approximately 95 per cent of the transfer of energy from the mean motion to the turbulence motion takes place within 3 diameters of the disk, in the region of the mean standing eddy. The measured mean ambient-pressure and mean total-pressure distributions, and the mean streamline pattern are presented in graphical form, as are the quantitative balances of the integrated momentum and mean-energy relationships. A stream function consisting of a continuous distribution of doublets is introduced to extend the radial limit of understanding of the flow characteristics to a very large if not infinite radius. Considerable attention is given to the problem of obtaining and interpreting turbulence-shear-stress data immediately downstream from the point of flow separation. The applicability of a local diffusion coefficient or virtual viscosity of the Boussinesq or Prandtl

type for relating the turbulence shear stress to the radial gradient of mean axial velocity is discussed. The Bernoulli sum and the energy changes along individual streamlines investigated in an associated study are incorporated herein to obtain a quantitative estimate of the local errors involved in the turbulence-shear-stress measurements.

**Preliminary Studies of the Wake of a Body With Zero Difference of Momentum Flux.** HORACIO ALBERTO CARUSO. M.S. Thesis, February 1963; Professor Rouse, adviser. The wake of a disk in a uniform air stream with a jet emerging from its center was explored by stagnation-tube traverses for the condition of a zero change of momentum flux. The mean-velocity profiles were found to assume a self-preserving form within a relative short distance from the disk. Based on the assumption of a straight-line velocity distribution, the interrelationship between various mean-flow characteristics including a volume-flux parameter was investigated by an algebraic procedure.

**Spillway Discharge at Other Than Design Head.** JOHN J. CASSIDY. Ph.D. Dissertation, June 1964; Professor Rouse, adviser. A method was developed for the numerical solution of steady, irrotational, free-surface flow over a known continuous lower boundary in a gravity field. In particular, the method involves the solution of finite-difference approximations—in the complex-potential plane—of the Laplace equation in terms of the inclination of the velocity vector. All geometric variables were specified in the physical plane, but, for subcritical approaching flow, the total head was unknown at the outset. However, it was possible, by comparison of successive iterations for the coordinates of the free-surface profile, to formulate an algorithm for correction of an assumed total head. Free-surface profiles, pressure distributions, and discharge coefficients were obtained for flow over three spillway shapes at five ratios of head to design head. The results compared favorably with experimental measurements. Boundary-layer characteristics were obtained experimentally for flow over a spillway model of standard shape. As a result it can be concluded that separation will not occur on a standard spillway unless heads greater than three times the designed are allowed; if the spillway is large, cavitation may occur at a much lower head than that for which separation occurs. Spillways which will not cavitate through the entire range of ex-

pected heads can be designed from the pressure-characteristic curves resulting from this study.

**Aspirative Efficiency of Chimney Shapes.** MAHESH C. CHATURVEDI. M.S. Thesis, August 1960; Professor Posey, adviser. The factors controlling the flow of air through a perforated pipe under flow of wind past it were analyzed. Experimental study of three chimney shapes and the effect of variation of size and number of holes was carried out. It was found that an aspirative velocity equal to 0.35 external velocity was obtained for a cylindrical chimney and it could be increased linearly by increasing the number of holes.

**Flow Characteristics at Abrupt Axisymmetric Expansions.** MAHESH C. CHATURVEDI. Ph.D. Dissertation, August 1962; Professor Rouse, adviser. The flow at abrupt axisymmetric expansions represents a typical case of separation at an abrupt change of boundary and was studied in detail for four half angles of expansion—15°, 30°, 45°, and 90°—to determine the characteristics and the dynamics of flow. The characteristics of the mean flow and the secondary flow such as the distribution of the mean velocity and pressure, the axial, radial, and tangential turbulence intensities, and the turbulent shear, were evaluated. The basic hydrodynamic equations of impulse-momentum and work-energy for both mean and turbulent motion were formulated for the conditions of the study. These were evaluated section by section, to provide a check on the measurements and to determine the pattern of separation, the development of the force field, and the dynamics of energy transfer from the mean motion through the turbulence toward its final form of heat. The experimental setup consisted of the abrupt expansion preceded by a bellmouth entry and followed by a uniform duct. The expansion was 4¼ inches and 8½ inches in diameter at the inlet and the outlet end, respectively, so that the expansion ratio was 1:2. The fluid used was air and the Reynolds number at the inlet was about $2 \times 10^5$. Additional independent measurements of head loss were also made on a water-pipe assembly.

**Turbulence Studies in the Wake Behind a Powered Surface Vessel.** CHARNG-NING CHEN. M.S. Thesis, February 1964; Professor Hubbard, adviser. Turbulence characteristics in the wake behind a powered surface vessel, under the condition of zero rate of change

of momentum, were studied by the aid of the IIHR constant-temperature hot-wire anemometer. The distributions of mean velocity and turbulence intensity were found to be unsymmetric. The maximum value of the longitudinal component of the turbulence intensity varies inversely as the distance to the 4/5 power. Depth of slipstream and turbulence dissipation were also investigated.

**The Application of the Bernoulli Theorem in Zones of Separation.** RENE CHEVRAY. M.S. Thesis, February 1964; Professor Rouse, adviser. A general discussion of the conversion of energy in flow with separation is presented through use of the Bernoulli equation for turbulent flow. The pertinent terms of the Bernoulli theorem are evaluated line by line for flow past a normal wall, for flow in pipes with 90° and 15° expansions, and for flow around a circular disk. The results, presented in graphical form for different sections along a streamline, show the role played by the eddy in a region of separation; production of turbulence in the transition zone; transfer of energy from one streamline to another; and, finally, loss of energy in the region of the eddy. More than elucidating the role of the eddy and checking on overall analysis, this thesis offers a method of predicting the values of the turbulent shear stresses.

**Effect of Radius of Curvature Upon Loss in Trapezoidal Equiradial 90° Open Channel Bend at Constant Slope.** SIE LING CHIANG. M.S. Thesis, January 1965; Professor Howe, adviser. The investigation of the effect of radius of curvature upon the loss in trapezoidal equiradial 90° open-channel bends leads to the conclusion that the larger the radius, the smaller the loss of head. Considering the curved channel only, the total head loss through the bend ($H_l$) and the loss of head due to the bend itself ($h_b$) are compared. The loss coefficients are also evaluated.

**Erosion Tests of a Protected Embankment Section.** KI-SHUN CHU. M.S. Thesis, June 1961; Professor Posey, adviser. A model fill made of fine sand was protected from scour by rock sausages placed over filter layers. The maximum head over the crest of the model reached as high as 14.4 times the mean diameter of the rock sausages. Types of failure observed were the lifting of upstream ends of the sausages and the creeping of the sausages when pulled by the rapid flow downstream. On the other hand, failure was rapid and occurred at a head of 2.4 times the mean particle diameter of

the top layer when rock sausages were omitted and only filter layers used. With sausages alone and no filter layers, failure was slow but started as soon as the water reached the crest level.

**Optimum Shape of a 90° Bend in a Rectangular Channel.** CARL ERNEST DENZLER. M.S. Thesis, February 1960; Professor Howe, adviser. An effective method of reducing head loss in 90° bends in rectangular channels is to widen the inside of the bend by increasing the inside radius. The shape for minimum head loss in a particular bend having a centerline radius-to-width ratio of 4.5, as well as a general discussion of the optimum shape of bends with other radius-to-width ratios, is presented herein. The experimental results are based on 52 tests conducted in the laboratory annex of the Iowa Institute of Hydraulic Research. A rectangular wooden channel, 5½ inches wide and 5 inches deep, was used. A 90° bend having a radius of 4½ channel widths was placed between a 30-foot-long upstream leg and a 36-foot-long downstream leg. Seven bends of varying widths were used, each with three different quantities of flow. The results were analyzed to obtain the bend shape that had minimum head loss. Velocity distributions were obtained for the important bend shapes as an aid to analyzing the head loss in bends.

**Effect of Change in Standard Deviation of Particle-Size Distribution on the Depth of Scouring.** LEONIDAS E. DIAMANDIS. M.S. Thesis, August 1960; Professor Brush, adviser. A continuation of previous studies performed by H. Rouse and E. M. Laursen with uniform sand. The effect of change in the standard deviation of particle-size distribution (in the range of $\sigma = 0.25$ to $\sigma = 0.70$) on the rate of scouring, similarity of profiles, and limiting velocity was studied. Nonuniformity limits scour but has no effect upon profiles.

**Distribution of Head at a Rectangular Conduit Outlet.** SATYA PRAKASH GARG. Ph.D. Dissertation, June 1965; Professor Rouse, adviser. The analytical solution of the problem involved the determination of the geometry of the free streamlines of the jet. A new method for solution of such problems has been developed in this paper. By the use of this method an improved approximation to the free-streamline geometry is obtained, proceeding from an assumed configuration, and better accuracy is achieved with each subsequent iteration. Solutions for flow through a two-dimensional

conduit at Froude numbers of 1, 2, 3, and 4 have been obtained by employing this method and programming it on an IBM 7070 computer. A relation between the location of the piezometric-head line at the outlet of the conduit and the Froude number has thus been determined. The effects of the geometry and the roughness of the conduit on the flow were evaluated by means of a series of experiments in which conduits of various width-depth ratios and with coatings of different sand sizes were used. The relation obtained from the relaxation solution has been extended to incorporate the effects of the resistance of the boundaries and the geometry of the conduit on the location of the piezometric-head line.

**An Experimental Study of the Turbulence in the Wake of a Body of Revolution.** P. J. L. Gear. M.S. Thesis, January 1965; Professor Hubbard, adviser. The early results of a continuing study of the wake of a 6-to-1 ellipsoid are presented. Measurements were made at a Reynolds number based on model length of $4 \times 10^6$, and close to the stern, of the mean flow characteristics and of the three components of turbulence intensity. A value of 0.074 for the total drag coefficient of the body was obtained through application of the momentum equation.

**Effect of Gate Slots Upon the Hydrodynamic Forces Acting on High-Head Gates.** Norbert M. Gillissen. M.S. Thesis, January 1965; Professor Naudascher, adviser. This investigation is a continuation of the studies done by Kobus and Rao. The downpull was obtained by graphical integration of the pressure distribution on the gate bottom. Oil-flow pictures of the flow pattern over the gate lip are presented for various gate openings and configurations of the slot.

**Transistorized Hot-Wire Anemometer and Linearizing Circuit.** John R. Glover. M.S. Thesis, August 1961; Professor Hubbard, adviser. Transistorized control circuits were employed to keep the temperature of a wire for use in air essentially constant, thus eliminating the need for consideration of the thermal lag of the wire. Also, by using constant-temperature operation of the wire the frequency response of the instrument was greatly increased. The nonlinear signal voltage developed by the wire was linearized by a

new method that increased the dynamic range of the instrument, which also increased its accuracy and reliability.

**Techniques for Detecting and Analyzing Unsteady-Flow Variables.** JOHN RICHARD GLOVER. Ph.D. Dissertation, June 1965; Professor Hubbard, adviser. The first three parts of this dissertation deal with the design and improvement of electronic instruments that are used for the detection and analysis of unsteady-flow variables. The last part is an analysis of the error, introduced by the averaging of the signal before squaring, in the measurement of power spectral density of unsteady-flow variables when the filter used in selecting the frequencies has a very narrow bandpass. The first of two instruments that have had their performance improved is the constant-temperature hot-wire anemometer. An increased signal-to-noise ratio has been achieved by reducing the regenerative or positive feedback in the control amplifier. Also, a linearizing circuit has been developed which is completely transistorized (no function generator) and temperature stable. The second instrument which has been improved is the one that measures the intermittency factor of a completely random signal, such as generated by a turbulence-detecting instrument. The improvement results because the smoothing filter normally required for pseudo-satisfactory operation, has been eliminated by including the slope of the signal in the control of the frequency-gating signal. The third instrument included as a part of this dissertation is an Unlimited-Time Integrator. The instrument is capable of integrating a signal for a period of time that is limited only by the unsteadiness of the system which is external to the integrator.

**Flow Characteristics in the Two-Dimensional Wake of a Flat Plate.** RICHARD GEORGE HAJEC. M.S. Thesis, February 1961; Professor Rouse, adviser. The distribution of mean velocity, mean pressure, fluctuating longitudinal component of velocity, fluctuating pressure, and correlation of the fluctuating velocity and pressure in a two-dimensional wake of a flat plate are presented and discussed. Special experimental equipment and technique are included in detail. Closely related to the vortices shed from the edges of the plate, a zone of maximum turbulence was found to occur within the mean separation pocket. At a distance from the plate equal to its width both the velocity and the pressure fluctuations reached

maximum values, and the minimum mean pressure was recorded as -1.85 times the dynamic pressure in the undisturbed stream. The lateral location of the peaks in the distribution of velocity and pressure fluctuations were found to correspond closely with the centerlines of the trails of vortices as determined by von Kármán.

**The Effect of a Change in Skewness of Particle Size Distribution on the Depth of Scour.** ABDUL HANNAN. M.S. Thesis, February 1962; Professor Brush, adviser. Five different mixtures of sand having the same mean diameter and the same standard deviation but different skewnesses were used to investigate the scour due to a submerged jet. The nondimensional scour profile was found to be independent of both time and skewness. Small secondary effects upon the scour phenomena were observed, and these were explained directly in terms of the distribution of particle sizes in the extreme size ranges.

**Flood Insurance.** GERALD R. HARTMAN. M.S. Thesis, June 1960; Professor Posey, adviser. The insurance and technical problems involved in a flood insurance program are discussed, using basic insurance principles and information relative to floods as guides. The Federal Flood Insurance Act of 1956 and its results are also discussed. Other approaches to the flood problem are summarized and suggestions to make flood insurance a reality are offered.

**The Variation of Loss Coefficient With Froude Number in an Open-Channel Bend.** SIKANDER HAYAT. M.S. Thesis, January 1965; Professor Rouse, adviser. The purpose of this investigation was to study the variation of loss coefficient with Froude number in an open-channel bend at different depth-width ratios. Since it was difficult to get the loss of head in a single bend with precision, six successive similar 90° bends were used in the experiment. The loss of head due to a bend was obtained after subtracting the loss of head in an equivalent straight channel from the total loss in a bend. The loss coefficient per bend was determined as a function of the Froude number from the ratio of loss of head to the velocity head at depth-width ratios of 1/4, 1/8, and 1/16.

**Fall Velocity of a Sphere in a Field of Oscillating Fluid.** HAU-WONG HO. Ph.D. Dissertation, June 1964; Professor Brush, adviser. In the application of the diffusion equation for sediments in a turbulent fluid, the fall velocity of the sediment particles is often

assumed to be the same as the fall velocity in a stationary fluid. The validity of the assumption has been questioned. In order to demonstrate the effect of the motion of the fluid on the fall velocity of sediment particles, the fall velocity of particles settling in a field of oscillating fluid was determined experimentally. It was found that the fall velocity of particles in an oscillating field of fluid was much lower than that in a stationary fluid. The numerical solution of the equation of motion of a settling particle has been found to be useful in estimating the fall velocity of a particle in an oscillating fluid.

**The Resistance of Piers in High-Velocity Flow.** TSU-YING HSIEH. M.S. Thesis, August 1962; Professor Rouse, adviser. An experimental investigation of the variation of the resistance coefficient of cylindrical piers in a rectangular channel was conducted. The resistance coefficient was determined as a function of the Froude number, of the relative depth of the oncoming flow, and of the relative spacing of the piers.

**An Experimental Study of the Vorticity in the Wake of a Body of Revolution.** LO-CHING HUA. M.S. Thesis, February 1963; Professor Landweber, adviser. The magnitude and direction of the velocity distribution in the wake of a prolate spheroid were determined from measurements with a 3-hole pitot tube. A procedure for analyzing the measurements, taking into account the turbulence in the wake, was developed and applied. For this purpose it was also necessary to measure the distributions of various turbulence stresses in the wake. From the resulting velocity-vector distribution it was then possible to compute the vorticity distribution as the curl of the velocity. These results may serve as a basis for a study of the mechanism of lift on a body of revolution.

**Energy Loss in Pipe Expansions.** THOMAS TSUNG-TSE HUANG. M.S. Thesis, February 1964; Professor Rouse, adviser. An experimental study was made to determine the effects of the variation of expansion angle, entrance condition, and Reynolds number on the over-all energy loss in pipe expansions. This investigation was an extension of the 1962 doctoral study by M. C. Chaturvedi. The half angles of expansions used in this experiment were 3½°, 7½°, 15°, 25°, 30°, 35°, 45°, and 90°. A bellmouth entry, an 11½-foot smooth brass pipe, and a 6-foot artificially roughened pipe preceding the

expansions were chosen to provide three different entrance conditions for the flow. The Reynolds number at the entrance section was varied over a range of $3 \times 10^4$ to $1.5 \times 10^5$. The value of the expansion ratio, $D_2/D_1$, was taken as 2, the same as that used in Chaturvedi's work.

**A Submerged Vertical Jet Beneath a Free Surface.** BRUCE W. HUNT. M.S. Thesis, January 1965; Professor Rouse, adviser. Profiles of the free surface above a three-dimensional, vertical, submerged jet were measured and plotted as a function of the momentum flux and nozzle submergence depth. The surface profiles were found to be almost geometrically similar for submergences greater than or equal to 16 nozzle diameters, and the relative centerline surface displacement was found to be nearly independent of the relative submergence depth for submergences greater than or equal to 25 nozzle diameters. In addition, an approximate analytical method for determining the centerline displacement of the free surface is given.

**Verification of Method of Determining the Viscous Drag of a Ship Model.** KENNETH KEY. M.S. Thesis, January 1965; Professor Landweber, adviser. Application of the Betz-Tulin method for measuring the viscous drag of a ship model in a previous work by Jin Wu resulted in an unexpectedly sinuous variation of the curve of viscous drag versus Froude number. Because of the importance of this curve in the usual procedure of predicting ship resistance from model tests, the experiment was repeated with refined equipment and improved calibration technique. The new results are somewhat less sinuous, but essentially confirm the variation previously found.

**Effect of Lip Shape Upon Hydraulic Forces on High-Head Gates.** HELMUT E. KOBUS. M.S. Thesis, February 1963; Professor Naudascher, adviser. The relative pressure distribution along the bottom and top surface of a vertical leaf gate at partial openings has been obtained from air-tunnel experiments. The effects of the angle of inclination of the bottom surface and of an extension of the downstream skinplate have been investigated. It was found that lip shapes with large angles of inclination of the bottom surface or large extensions of the downstream skinplate yield the most favorable conditions with respect to the mean downpull. Violent

pressure fluctuations were observed near the transition to complete separation of flow from the gate lip. The conditions for the development of subatmospheric pressure along the gate lip were examined and analyzed.

**Heat Transfer from Fine Wires in Flowing Liquids.** ALBERT Y. KUO. M.S. Thesis, January 1965; Professor Hubbard, adviser. Because of the instability of a hot-wire anemometer in water, the factors influencing heat transfer from an electrically heated wire in flowing liquids were investigated. Kramers' formula was shown to agree with experimental results for filtered fresh water and unfiltered mineral oil. In salt water, the rate of heat transfer decreased with increasing electrical conductivity. Deposition was found on the wire after being used in highly concentrated salt water. The deposition of the impurities in unfiltered water invariably reduced the rate of heat transfer.

**Effect of Particle Size Distribution on Characteristics of the Suspended Load.** TSE MIN LEE. M.S. Thesis, June 1960; Professor Brush, adviser. This study was to investigate the effect of the bed-material size distribution on (1) the concentration of the suspended load, (2) the size of the material moving as suspended load, and (3) the height of dunes which form on the beds of alluvial channels for equal hydraulic conditions. Two sands, each with the same mean size and skewness but with different standard deviations, were used as bed materials. Theoretical analysis of the suspended load was incorporated. The effect of bed configuration on the channel resistance was studied. The sampling techniques were also discussed. Use of the experimental results to predict the size distribution and concentration of suspended load in streams was discussed. Also, recommendations were made for future investigations.

**Distribution of Velocity and Pressure at a Submerged Outlet.** YA-TAI LIN. M.S. Thesis, August 1960; Professor Rouse, adviser. An experimental study was undertaken for the purpose of tracing the relationship between the pressure distribution around a submerged pipe outlet and the velocity distribution across the outlet for airflow of high Reynolds number. As the velocity variation across the outlet was increased, the pressure loss along the pipe was found to decrease because of a partial compensation by a longitudinal

decrease in momentum flux, and the pressure at center of the outlet, which was invariably lower than the wall pressure, was found to change from positive to negative values. Studies were also made of the deflection of streamlines, and a functional relationship was derived between the inward velocity along the wing wall and the mean velocity.

**Overturning Moments on a Flashboard Mounted on a Parabolic Spillway Crest.** ALBERTO LIZARRALDE. M.S. Thesis, February 1962; Professor Howe, adviser. In this investigation the overturning moments on a flashboard mounted on a parabolic spillway crest are determined for various rates of flow and submergence ratios. Pressure measurements are made on the downstream and upstream faces of the flashboard. The results are given on a graph which shows the dimensionless relationship between the overturning moments, the submergence, and the rate of flow. A comparison of the moments obtained through the range of the experimentation with those computed assuming upstream hydrostatic distribution and downstream atmospheric pressure is included.

**A Preliminary Investigation of the Pressure Fluctuations in the Vicinity of Normal Walls.** FREDERICK A. LOCHER. M.S. Thesis, January 1965; Professor Naudascher, adviser. Spectral densities of the pressure fluctuations at three points in the vicinity of normal walls were examined to determine the range of frequencies over which enough energy was available to be considered as a possible source for the excitation of vibrations. Approximately the same dominant frequency was found at two points: (1) in front of the wall, and (2) at the end of the separation pocket behind the wall. The dominant frequency did not appear to be affected by the thickness of the walls which were investigated in this study. Development of the electrical network and analysis of the signal representing the fluctuating pressure are presented. The transient response of filters is qualitatively discussed, showing that the use of a squaring circuit in the spectral analysis of this particular type of signal yields erroneous results.

**The Effect of Flood Magnitude on Unit Hydrograph Characteristics.** JAMES LAWRENCE LONG. M.S. Thesis, February 1962; Professor Howe, adviser. This thesis is an analysis of the factors affecting the unit hydrograph with special emphasis on the effect of flood mag-

nitude on the peak of the distribution graph and on the time of occurrence of the peak with respect to the center of precipitation excess. Included is also the study of twenty-four hydrographs from two different drainage basins involving runoff volumes varying from 0.6 to 5.75 inches and peak flows from 2,800 to 36,000 cubic feet per second.

**Experimental Investigation of an Annular Jet Traveling Over Water.** JOACHIM K. MALSY. M.S. Thesis, August 1960; Professor Mack, adviser. In connection with the development of an air-cushion vehicle, an experimental study was conducted of the flow phenomena occurring when a 7-inch-diameter annular nozzle, with a ⅛-inch air gap, was towed over water. The height above the water surface, the speed of tow, and the rate of air discharge were varied, pressures on the base plate of the annular nozzle were measured, and the resulting lift was computed. It was observed that the jet approached the water surface at a steeper angle than analysis of the effect had indicated, and that the surface disturbances were larger than predicted. A vortex ring, observed in the water near the free surface in the region of deflection of the air jet, is believed to account for these phenomena.

**The Instability of Stratified Flow.** GEORGE HENRY MITTENDORF. M.S. Thesis, February 1961; Professor Rouse, adviser. Two miscible fluids of different density were allowed to intrude into one another in a closed conduit at a given slope. Propagation of the two resulting fronts was observed by means of thermistors. Interfacial conditions were recorded photographically. Regardless of slope, the celerities of the two fronts became noticeably different for differences in density larger than one per cent. The onset of turbulence at interface, as well as the thickness of interlayer resulting from turbulence, were correlated with the Froude and Reynolds numbers of the flow.

**The Effect of a Free Surface Upon the Velocity Distribution of a Submerged Jet.** JAMES JOSEPH MROSS. M.S. Thesis, February 1960; Professor Hubbard, adviser. The object of this investigation was to determine the flow characteristics of a jet emerging from a streamlined nozzle parallel to and at a variable distance below a free surface. In an initial zone, the approximate extent of which is calculated from the intersection of a cone of 28° apex with the free

surface, the results for a free jet were found to apply as a very close approximation, particularly with regard to the velocity profiles and the volume, momentum, and kinetic-energy flux. In a subsequent zone, the point of maximum velocity was found to approach the free surface gradually and the velocity to decrease at a lower rate than in the first zone. Despite this change in velocity profile, the flux of volume and kinetic energy continued to vary in close agreement with the respective trends obtained for a jet far from a boundary.

**Prediction of Runoff Frequency Based on Precipitation and Infiltration Frequencies.** SRINIVASAN MUKUNDAN. M.S. Thesis, February 1963; Professor Howe, adviser. A study based on the assumption, Runoff frequency = Precipitation frequency × Infiltration frequency, was made on two watersheds: of 388- and 792-square-mile areas with 56 and 45 years of record, respectively. The observed surface runoff was compared with the estimated runoff based on combinations of precipitation and infiltration frequencies and did not show any agreement. The frequency of estimated runoff was found to be far greater than the observed frequency.

**Characteristics of Separation at Conical Afterbodies.** SAMPATHIENGAR NARASIMHAN. Ph.D. Dissertion, June 1965; Professor Rouse, adviser. The mean-flow and turbulence characteristics of motion following separation from a conical afterbody were investigated for various combinations of initial boundary-layer thickness and angle of convergence of the boundary. For a given boundary geometry, the rate of turbulence production and the base drag increase with decrease in the value of the boundary-layer thickness, and the increasing importance of the role of the inertial effects of turbulence causes similarity profiles to be achieved earlier. For a given boundary-layer thickness, the flow characteristics remain almost unchanged for cone angles greater than 60°. When the cone angle is reduced progressively to 50°, the rate of turbulence production increases and the size of the eddy pocket decreases. Upon reattachment of the separation profile to the boundary of the tailpiece, any further reduction in the cone angle causes the cumulative turbulence production to decrease continuously.

**Establishment of Flow at an Abrupt Inlet.** IRVATHUR V. NAYAK. M.S. Thesis, August 1960; Professor Rouse, adviser. The important

characteristics of the zone of flow establishment at an abrupt inlet were studied over the critical range of Reynolds number (400 to 5400). The loss coefficient was found to vary with **R** in a similar fashion to the drag coefficient of an immersed body or discharge coefficient of an orifice or Venturi meter. The resistance coefficient $f$ was found to differ consistently from the theoretical values given by the Poiseuille and Blasius equations.

**Cavitation and Pressure Fluctuation Behind a Bluff Body With and Without a Trailing Splitter Plate.** ARTHUR D. NEWSHAM. M.S. Thesis, February 1963; Professor Rouse, adviser. The lateral oscillation of the flow behind a bluff body can be prevented by introducing a splitter plate in the wake of a normal plate. The disappearance of the oscillating flow pattern changes the pressure distribution and, therefore, also affects the conditions in which cavitation first appears. The mean pressure distribution was determined along the line of symmetry, and the spectral density of the pressure fluctuation was recorded at three points in the wake. When the splitter plate was introduced, the dominant frequency associated with the flow around a bluff body was no longer evident and the pressure fluctuation was more random.

**Three-Dimensional Turbulent Boundary Layer.** F. S. A. PAVAMANI. M.S. Thesis, August 1960; Professor Landweber, adviser. Measurements were made in an air tunnel on an ellipsoid of principal axes 5 feet, 1 foot, and 0.25 foot at a wind speed of 60 fps. Velocity profiles in the boundary layer, the direction of flow, and the total pressure at the surface were measured. The data were analyzed to determine the pattern of velocity variation within the boundary layer, the variation of wall shear and boundary-layer thickness, the applicability of the inner law, and the angle of flow at various points, and to detect cross flows and separation. It was found that the boundary-layer thickness decreases and the shear stress at the wall increases with increasing curvature in the transverse direction. The inner law of the boundary layer seemed to be valid at least where the curvature was small.

**Sediment Transport in a Pipe With Secondary Circulation.** ALAN LEE PRASUHN. M.S. Thesis, June 1963; Professor Brush, adviser. The use of short vanes placed at regular intervals along the top of a pipe at an angle of attack was investigated as means for increasing

sediment transport with a minimum power increase. The vane angle, the sediment discharge, and the fluid discharge were varied independently, and observations were made of the over-all head loss. It was found that the maximum head-loss reduction was achieved when the vanes were at an angle of 20° with the pipe axis. The head loss-reduction was greatest in the region where the head loss was a function of the sand concentration, but for the region where the head loss was independent of sand concentration, or nearly so, no head-loss reduction was possible.

**Vortex Over a Horizontal Orifice.** KOTHA K. RAO. M.S. Thesis, August 1960; Professor Posey, adviser. As a continuation of H. C. Hsu's thesis "Vortex over Outlet" (1947) the variation of the discharge coefficient of a circular horizontal orifice with vorticity factor was investigated. The vortex was created and controlled by a simple arrangement of inclined water jets introduced over the free surface in a 3-foot-diameter tank fitted with a 3-inch circular orifice at the bottom. An interesting condition of instability leading to the formation of a whirling type of surge was observed to develop during some of the runs.

**Boundary-Layer Development at Curved Entrances of Conduits.** PALEPU V. RAO. Ph.D. Dissertation, August 1964; Professor Rouse, adviser. With the aim of studying how the energy reduction occurs in a conduit inlet shaped according to potential theory, boundary-layer measurements were made in a nonrecirculating air duct with circular, square, and rectangular types of inlet. The compound elliptical shape of the U.S. Corps of Engineers was adopted in all three cases. The effect of conduit Reynolds number on the growth of the laminar and turbulent boundary layers in the inlet portion of the conduit was studied for all three types of inlet. The potential velocity distribution for the axisymmetric inlet was obtained by solving the difference equation for the Stokes stream function. The laminar-boundary-layer growth was calculated by the finite-difference method of Görtler and Witting. Proper turbulent-boundary-layer growth in the inlet was obtained by artificial roughness. Greater energy reduction due to secondary motions at the corners of the noncircular inlets was noticed for both laminar and turbulent boundary layers. The energy reduction in the inlet was found to be highest with a rectangular inlet and least for a circular one. Graphs are given showing coefficients of energy re-

duction as functions of relative distance into the inlet and Reynolds number.

**Effect of Gate and Conduit Geometry Upon the Hydrodynamic Forces Acting on High-Head Gates.** RAGAM PANDU RANGANADHU RAO. M.S. Thesis, August 1963; Professor Naudascher, adviser. In an extension of Kobus' study (M.S. thesis, 1963) of the effect of lip-shape on hydraulic downpull, the effect of the relative upstream radius of the gate lip and of the relative conduit height upon the dimensionless downpull coefficients was made. The determination of the susceptibility of a given gate and conduit geometry to development of subatmospheric pressures along the gate bottom and to unstable flow conditions was also made. Results showed that the downpull decreases with an increase in the upstream relative radius of the gate lip and increases with an increase in the relative conduit height.

**Drag Coefficients of Flat Plates Oscillating Normally to Their Planes.** MUHAMED RIDJANOVIC. M.S. Thesis, August 1960; Professor Landweber, adviser. A flat plate oscillating normally to its plane may experience much greater drag than one in steady flow. In the present work a previous two-dimensional study of this phenomenon is extended to the three-dimensional case, for plates of various aspect ratios. It was found that the mean drag coefficients for small amplitudes of oscillation may be 5 times as large as for steady flow. This result is explainable by the formation of vortices at each cycle of the oscillation and incomplete development of the wake. A consistent family of drag curves, which shows a trend toward the drag coefficient for a flat plate in steady flow at large oscillation amplitudes, was obtained.

**Wake With Zero Change of Momentum Flux.** MUHAMED RIDJANOVIC. Ph.D. Dissertation, August 1963; Professor Rouse, adviser. This study was undertaken for the purpose of obtaining an insight into the flow characteristics and of tracing the energy changes in a wake simulating that of a self-propelled body. The experiments were carried out in an air tunnel with zero pressure gradient, a stationary disk emitting a jet into its wake in the direction of flow. The momentum flux of the jet was selected so as to reduce to zero the difference in momentum flux between sections well upstream and downstream from the disk. The detailed investigation was car-

ried out in the region from $x/D = 4$ to $x/D = 130$ for a Reynolds number of approximately $6 \times 10^4$. The results for mean ambient- and total-pressure distribution, mean velocity distribution, and turbulence-intensity and shear-stress distributions are presented graphically. Three zones of flow with basically different flow characteristics were found: first, an eddy zone, with the most typical characteristic of high rate of mean-energy loss where practically the entire energy input of the jet is converted into turbulence; second, from $x/D = 4$ to $x/D = 50$, a zone associated with a high rate of change of all flow characteristics in the axial direction due to interaction of fluid between neighboring zones of positive and negative velocity defect; this leads rapidly toward conditions of nearly uniform and isotropic flow in the third zone beyond $x/D = 50$.

**Surface Resistance as a Function of the Concentration and Size of Roughness Elements.** JOHN ARTHUR ROBERSON. Ph.D. Dissertation, August 1961; Professor Rouse, adviser. A method was developed which allows the surface resistance to be computed for flow in a conduit which is roughened with cubical roughness elements when basic data defining the roughness are given. The relative height of cube and cube concentration were the parameters which were used to define the roughness. The surface resistance is the sum of the viscous shear at the smooth wall and the drag on the roughness elements. Both of these resistance terms, however, are also functions of the mean boundary level and velocity distribution, and the latter, in turn, is a function of the over-all resistance. In order to achieve a solution, it was necessary to write an equation for each variable in terms of the appropriate remaining variables, and these equations were then solved for the desired resistance functions. The solutions were shown to be valid to the extent that they followed the trend of available experimental results. The experimental results were for various concentrations, the highest of which had 13 per cent of the boundary covered with cubes.

**The Stability of Stratified Flows on Nearly Vertical Slopes.** WILLIAM M. SANGSTER. Ph.D. Dissertation, June 1964; Professor Macagno, adviser. The interfacial stability of the two-dimensional counter-current flow of two incompressible fluid layers of differing density, viscosity, and thickness confined between parallel solid boundaries was investigated for very steep slopes. An eigen-value

problem resulted from the attempts at a power-series solution of the governing Orr-Sommerfeld equations and imposition of the appropriate boundary conditions. Expansion of the resulting determinant provided a relationship among the celerity and wave length of the applied disturbance and the Reynolds number of the primary flow. Graphical results of a computer solution for this relationship are presented. Limitations in the analysis required that the slopes be greater than 85° and the thickness of the lower stratum be always greater than that of the upper. A more stable flow results when (a) the slope is reduced, (b) the density ratio is increased, (c) the viscosity ratio is brought closer to unity, (d) the thickness ratio is brought closer to unity, or (e) the interfacial tension is increased.

**Optimum Shape of a 90° Bend in a Trapezoidal Channel.** ANNAMALAI SHANMUGAM. M.S. Thesis, August 1963; Professor Howe, adviser. Model studies conducted to evolve the optimum shape of a 90° bend in a trapezoidal channel for minimum head loss under conditions of subcritical flow showed that the loss of head is a minimum when the inner and outer curves are equiradial. In an equiradial bend with a ratio of radius of curvature to normal bed width of 5.5, the energy loss was found to be only half that encountered in a conventional constant-width bend. With decreasing ratio of center-line radius to normal bed width below 5 the loss of head increased.

**Overturning Moments on a Flashboard.** HSING-HUA SHIH. M.S. Thesis, February 1964; Professor Howe, adviser. Changes of slope of a straight downstream apron of a spillway had been found by Bacci and Schultz to have certain effects upon the overturning moment of a flashboard. Lizarralde adopted the Corps of Engineers' Standard Spillway formula and tested one particular model. The present investigation is concerned with another model which is designed according to the same standard formula but based upon a small design head. The result is that while the general geometry is similar to Lizarralde's model, the downstream apron inclination has been increased. Detailed comparison has been made between the present results and those of Lizarralde, the present data affording a means of rational flashboard design.

**Diffusion of Sediment in a Submerged Jet.** SURYA RAO SINGAM-

SETTI. Ph.D. Dissertation, January 1965; Professor Rouse, adviser. Diffusion of sediment particles in a vertical, axisymmetric, sediment-laden, submerged jet directed downward into stationary water was studied. From the measurements of mean velocity distribution and mean sediment-concentration distribution, the ratio $\beta$ of the eddy diffusivity for momentum was obtained. It has been found that in the region of measurements the parameter $\beta$ has a limiting value of about 1.2 within the Stokes range, and it increases with increase in the particle Reynolds number for the range covered in the experiments. These results have been explained by physical considerations regarding the inertial and gravitational effects on the motion of sediment particles in turbulent flow, in which the fluid motion in the eddies is circulatory rather than linearly oscillatory. Moreover, it is expected that $\beta$ increases with increase in the particle Reynolds number only so long as the fall velocity of the sediment particles is less than the rms value of turbulence fluctuations in the direction of fall; beyond a certain value of the ratio of the fall velocity to the rms value of turbulence fluctuations, $\beta$ decreases with increase in the particle Reynolds number.

**Irrotational Flow Over Weirs.** THEODOR S. STRELKOFF. Ph.D. Dissertation, June 1962; Professors Rouse and Landweber, advisers. The problem of two-dimensional, irrotational flow over a vertical, sharp-crested weir is expressed, exactly, by an integral equation, derived with the aid of conformal mapping and singularity distributions. A numerical procedure for checking trial-and-error solutions of the equations is programmed in Fortran language for automatic calculation on a high-speed, electronic, digital computer—either the IBM 704 or IBM 709. The resulting approximate solutions are presented in the form of flow profiles and discharge coefficients for head-to-height ratios h/w = 0.14, 1.15, 2.11, 4.36, 10.30. Available experimental data for comparable geometries are plotted on the same graphs to indicate the effects of viscosity and surface tension present in real flows. Inaccuracies, infeasible to reduce by trial and error, are shown to be present in the final results. The basis of an iterative procedure for solving the integral equation more accurately and less tediously is proposed and partially developed.

**Air-Tunnel Study of a Meander Model.** HENRY WILLIAM TIELEMAN. M.S. Thesis, February 1964; Professor Naudascher, adviser.

The purpose of this study was to obtain the longitudinal and transverse velocity distribution in a curved conduit, with a central angle of bend of 90 degrees. The results were compared with the corresponding data obtained from the open-channel model. Reasons are given for the discrepancies between the results of the two models.

**Drag of an Oscillating Plate in a Stream.** MING-TE TSENG. M.S. Thesis, January 1965; Professor Landweber, adviser. The drag coefficients of three flat plates with different aspect ratios, oscillating in a stream, were determined. The drag equation was derived on the basis of linear damping and nonlinear restoring force. The results showed that the values of the drag coefficient depend strongly on the current velocity. An attempt was also made to examine the effect of including nonlinear and damping terms in the analysis of the oscillation data for determining the drag coefficients. The results showed that, when a plate was oscillating in a fluid at rest, the refinement of the analysis beyond the assumption of linear restoring force and simple harmonic motion was unnecessary.

**Added Masses of Vibrating Elastic Bodies.** RICHARD GLENN WARNOCK. Ph.D. Dissertation, February 1964; Professor Landweber, adviser. The effect of the surrounding fluid on the natural frequencies of a vibrating ship is presently computed by an approximate two-dimensional theory known as strip theory. A more exact three-dimensional theory, which employs the kinetic energy of the fluid in the Lagrangian equations of the vibration, is illustrated by application to a sphere, a vibrating string, and a free-free cylindrical bar of finite length. Numerical calculations for an aluminum bar of length-diameter ratio 10 show close agreement with two-dimensional strip theory.

**The Separation of Viscous Drag and Wave-Making Drag.** JIN WU. M.S. Thesis, February 1961; Professor Landweber, adviser. Towing tests of ship models are generally conducted in water, and difficulty arises in satisfying the conditions for exact dynamical similarity. In order to overcome this difficulty, the ship is then tested by the Froude procedure. A theoretical possibility of separating the viscous and wave drag of ship forms was suggested by Tulin. This thesis is essentially the detailed description and the experimental proof of Tulin's method.

**Measurement of Viscous Drag of Ship Forms.** JIN WU. Ph.D. Dissertation, August 1964; Professor Landweber, adviser. An "exact" expression for the viscous drag was derived, on the basis of which it became possible to evaluate the accuracy not only of the Betz-Tulin's formula but also of two alternative, approximate versions suggested by the "exact" formula. The validity of these three approximate expressions was then checked experimentally by means of wake surveys. The theoretical study, experimental investigation, and numerical evaluation of the turbulence effects on the viscous-drag formula and measurements are also presented in this work. Subsequently, with this method of measuring viscous drag, the actual variation of viscous drag with Froude number was investigated experimentally. Finally, a practical, routine technique for making viscous-drag measurements by using electronic sensing device and recording and computing equipment is suggested.

**Characteristics of Subcritical Flow in a Meandering Channel.** BEN-CHIE YEN, Ph.D. Dissertation, June 1965; Professor Naudascher, adviser. The flow in a meandering channel is complicated by its curvilinear characteristics. Consequently, spiral motion and superelevation develop, and the velocity and boundary-shear distributions are modified. Through an approximate theoretical solution and experiments in a fixed-bed model of constant radius, central angle, and uniform cross section, the influences of the Froude number, and the width-depth ratio of subcritical flow with sufficiently high Reynolds number in a relatively wide meandering channel were determined. The velocity and boundary-shear distributions, the superelevation, and the growth and the decay of the spiral motion were studied in detail through analysis of the experimental results. The turbulence intensity of the flow was also measured. Experimental results are presented in generalized form.

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