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Minutes of the Meeting of the Division of Fluid Dynamics at Salt Lake City, Utah, June 25, 26, 27, 1952.

THE Division of Fluid Dynamics of the American Physical Society held its spring meeting at the University of Utah, Salt Lake City, at a three-day session on June 25, 26, and 27, 1952. The invited papers are listed below in the symposia program. There were thirty contributed papers, abstracts of which are contained below.

J. HOWARD MCMILLEN, *Secretary*
U. S. Naval Ordnance Laboratory
White Oak, Maryland

Symposium on Explosion Phenomena (Henry Eyring presiding)

1. Flames and Detonations. J. O. HIRSCHFELDER, *University of Wisconsin.*

2. Detonation Equation of State. M. A. COOK, *University of Utah.*

3. Fracturing Under Impulsive Loading. J. S. RINEHART, *NOTS, Inyokern.*

4. Damaging Air Shocks at Large Distances from Explosions. E. F. COX, *Sandia Corporation, Albuquerque.*

Symposium on Shock Waves (J. H. McMillen presiding)

1. On Shock Wave Phenomena: Aerothermodynamic Interaction. R. J. SEEGER, *National Science Foundation.*

2. Boundary Disturbances in High Explosive Shock Tubes. R. G. SHREFFLER, *Los Alamos.*

3. On Strong Shock Waves. E. L. RESLE, JR., H. PETSCHEK, S. C. LIN, AND A. KANTROWITZ, *Cornell University.*

4. Shock Waves in Spark Discharges in Gases. R. G. FOWLER, *University of Oklahoma.*

Symposium on Hydrodynamics and Jets (F. T. Rogers, Jr. presiding)

1. Hydrodynamical Theory of the Origin of Multiple Star Systems. R. W. STEWART AND G. J. ODGERS, *Pacific Naval Laboratory and Dominion Astrophysical Observatory, Victoria, B. C.*

2. Magnetohydrodynamics. W. M. ELSASSER, *University of Utah.*

3. Structure of a Two-Dimensional Supersonic Jet. D. BERSHADER AND D. C. PACK, *University of Maryland and University College, Dundee, Scotland.*

Special Evening Lecture

1. Research, Development, and Guided Missiles. R. E. GIBSON, Director, *Applied Physics Laboratory, Johns Hopkins University, Silver Spring, Md.*

Contributed Papers (R. J. Seeger, L. B. Linford, and F. N. Frenkiel presiding)

1. An experimental Investigation of Spinning Detonation. HERBERT T. KNIGHT AND RUSSELL E. DUFF, *Los Alamos Scientific Laboratory.*—Experimental work is reported which clarifies several features of the complex phenomenon of spinning detonation. The pitch-diameter ratio for spin in the carbon monoxide-oxygen system was found to be essentially independent of the initial percentage of carbon monoxide. The shape of the shock wave of a spinning detonation was determined by photographing the shock induced motion of a thin foil stretched across the detonation tube. The shock wave was found to be made up of at least two parts meeting at an angle near a diameter of the tube. During attempts to produce spinning detonation in large tubes it was found that wake confinement was essential to the propagation of this detonation. Finally, moving film photographs of a spinning detonation were taken through a slit perpendicular to the axis of the tube. These pictures showed a sinusoidal wave corresponding to a luminous disturbance moving around the tube at constant angular velocity. The nearly horizontal striations characteristic of the usual photographs of spinning detonation are produced by this disturbance passing a longitudinal slit on the detonation tube. In general the results of these experiments are in agreement with the hydrodynamic theory of spinning detonation proposed by Fay.

2. Measurement of Reaction Time in a Detonating Liquid. T. P. COTTER, *Los Alamos Scientific Laboratory.*—Detonation propagating through a homogeneous explosive consists of a strong shock followed by an induction period of comparatively slow reaction which culminates in a burst of vigorous reaction accompanied by thermal luminosity. The duration of the induction period is measured directly by observing the refraction of an inclined plane detonation wave through a thin plate of inert material which has been immersed in a transparent liquid explosive. A photograph of the steady-state refraction region showing both the deflection of the plate face by the shock and the onset of luminosity in the explosive is obtained by employing a rotating-mirror camera to hold the refraction region image stationary on the film for the appropriate exposure time. The perturbation of detonation by the plate can be corrected by choice of plate material and refraction angle and by extrapolation to zero plate thickness. The measured induction time of detonating nitromethane is roughly 0.1 microsecond. Induction times varying one hundred-fold about this value were produced following initiation by shocks of various strengths. Addition of sensitizer such as pyridine decreases the induction time markedly, but desensitizer such as benzene does not increase it.

3. Determination of Detonation Pressures From Flash Radiographs. J. N. DEWEY, H. I. BREIDENBACH, JR., AND J. W. GEHRING, JR., *Aberdeen Proving Ground.*—The observation of shock and material velocities in a material in contact with a steady state detonation gives a direct determination of the pressure on the surface of the material. When the detonation front in an explosive in contact with a metal is perpendicular to the metal surface, the compression of the metal results in an expansion of the detonation gases reducing the pressure on the metal surface below the detonation pressure. When the angle of incidence of the detonation on the metal, ϕ, is given by $\tan(\phi_o+\delta)=D\tan\phi/a_d$, where δ is the angle between the compressed and original metal surfaces, D is the detonation velocity, and a_d the velocity of sound behind the front, there is no rarefaction nor compression in the detonation gases at the surface of the metal and the pressure on the surface is the detonation pressure. Unfortunately, it is impossible to observe rarefactions small enough to permit accurate determination of a_d directly from a determination of ϕ_o. However, combination of the study of the effect of varying ϕ with observation of the shock fronts and mass velocity in the metal serves to determine both the detonation pressure and the properties of the metal under very high stresses. An approximate determination of the position of the shear front as well as the compression front is required for computation of the pressure. Another source of error is introduced by the small radius of curvature of the compression front in the metal directly behind the detonation front. Pressures and angles of the compression front at values of ϕ from O to those at which a shock forms have been determined using Pentolite and a magnesium alloy. A preliminary value of the detonation pressure slightly exceeds the computed, 2.1 $\times 10$ in. dynes/cm^2, but this may result from an underestimate of the shear angle, which it is hoped to determine more precisely in other experiments.

4. Limiting Conditions for Jet Formation in High Velocity Collisions. J. M. WALSH, R. G. SHREFFLER AND F. J. WILLIG, *Los Alamos Scientific Laboratory.*—The high velocity collision of two solids is discussed as a problem in compressible fluid hydrodynamics. Such collisions may conveniently be divided into jetless and jet-forming categories. A theory is presented which describes flow in the collision region for the jetless case, and determines a critical collision angle (as a function of material velocities and equation-of-state properties of the materials) above which a jet must arise from the collision.

5. Jetless and Jet-Forming Collisions of Explosive-Driven Metal Plates. F. J. WILLIG, R. G. SHREFFLER, AND J. M. WALSH, *Los Alamos Scientific Laboratory.*—The experimental study of solid collisions utilizes metal plates driven by high explosives, the collision process being recorded with a high speed smear camera. Two experimental arrangements are used, and data for collisions employing Dural, mild steel, brass, and lead are presented. Jetless and jet-forming collisions are observed, and critical angles separating the two types are compared with theoretical predictions. Agreement seems satisfactory to indicate that the theory is valid.

6. Free Surface Properties of Explosive-Driven Metal Plates. W. E. DEAL AND R. G. SHREFFLER, *Los Almos Scientific Laboratory.*—A photographic method is presented for the determination of the free surface properties of metal plates moving at the extreme velocities obtained by high explosive acceleration. The determination of the free surface velocity of plane surfaces is emphasized. Specific results using brass plates driven by Composition *B* are cited. Photographic techniques and methods for reduction of data from the photographic record are described. The more qualtiative features of the free surface motion are mentioned and representative pictures from the cameras records are shown. An extension of the technique to the study of various free surface phenomena associated with both plane and curved surfaces is indicated.

7. Fast Metal Jets. F. J. WILLIG, *Los Alamos Scientific Laboratory*

8. Surface Motion Associated with Obliquely Incident Elastic Waves.* JOHN PEARSON AND JOHN S. RINEHART, *U. S. Naval Ordnance Test Station, Inyokern, China Lake, California.*—Well-known laws which govern the reflection of elastic waves that strike free surfaces obliquely are summarized. These are used to deduce particle motion at the free surface. A number of numerical computations are presented in the form of tables and graphs for the case of an incident longitudinal wave. Considerations indicate that, for oblique incidence, the particle motion at the surface will not, in general, be perpendicular to the surface. The data are expected to be of value in the solution of problems connected with impulsively loaded bodies such as metal-explosive systems.

* Work partially supported by the ONR.

9. Transient High Amplitude Waves Through Steel.* WILLIAM A. ALLEN, *Michelson Laboratory, U. S. Naval Ordnance Test Station, Inyokern, China Lake, California.*—An optical technique, reported in a previous paper[1] has been used to measure surface oscillations on a series of thick, circular steel plates while they deform under explosive attack. Analysis of many photographic records indicates the presence of elastic, plastic, and shear waves. The methods used in data analysis will be discussed briefly. Data will be presented on amplitude of oblique wave reflection from a free surface, particle velocities at a free surface, and attenuation of wave amplitude.

* Work supported by Armament and Mechanics Branches, ONR.

[1] W. A. Allen and C. L. McCrary, Phys. Rev. **85**, 769 (1952).

10. Numerical Solution of the Equations for a Discrete Model of a Spherical Blast. T. S. WALTON, *U. S. Naval Ordnance Laboratory.*—A sphere of perfect gas at uniformly high pressure and temperature is allowed to expand suddenly into a homogeneous atmosphere. The continuous distribution of matter is approximated by partitioning the medium with a set of expansible, concentric spherical shells in which all the inertia resides, each chamber being filled with an inertialess but otherwise perfect gas in thermodynamic equilibrium. To produce the required entropy changes wherever shocks develop, an artificial dissipative mechanism was introduced.[1] The system of differential-difference equations pertaining to this dynamical model was integrated on the IBM Card-Programmed Calculator, starting with an internal pressure of 12.82 atmospheres and an absolute temperature 3.24 times that of the surrounding atmosphere. Besides the outward-moving shock which originates at the gas-air interface, the computation revealed the presence of an inward-moving shock wave which follows behind the rarefaction wave and converges toward the center of the sphere with ever increasing pressure ratio. A minimum pressure of 0.008 atmosphere was computed at the center just before the arrival of the interior shock.

[1] J. von Neumann and R. D. Richtmyer, J. Appl. Phys. **21**, 232 (1950).

11. The Effect of Charge Radius on Detonation Velocity. R. B. PARLIN, C. J. THORNE, D. W. RONINSON, *University of Utah.*—An analytic treatment of the effect of radial expansion on the velocity of propagation of a detonation wave in attempted. The resulting equations, together with auxiliary functions necessary for application to experimental data, are given. The approximations involved are discussed in terms of possible refinements in the treatment. Experimental data is applied to the results with reasonable consistency.

12. The Generation of Convection in a Planetery Atmosphere. Jean I. King, *University of Utah.* (Introduced by W. M. Elsasser).—A planetary atmosphere which absorbs partially in the infrared and is transparent in the visible and ultraviolet regions of the spectrum will, under radiative equilibrium, have a temperature decreasing monotonically with height. Such conditions prevail in the lowest 10 km of the terrestrial atmosphere and apparently on Mars. Equilibrium temperature distributions have been calculated for various line and band models of the absorption spectrum assuming the spectral lines are pressure-broadened. All the models show a steep temperature gradient near the lower boundary which is convectively unstable. Using these data, one can determine the height of this convective zone from a knowledge of the physical structure of the atmosphere. Results of this analysis shows that a planet with a completely quiescent atmosphere cannot exist.

13. On the Motion of Elliptical Vortices. Henry C. Alberts, George A. Coulter, and Charles M. Warden, *Aberdeen Proving Ground.*—When a shock wave is diffracted by an $\frac{1}{8}$-in. slit, one of the phenomena observed is the formation of elliptical vortices at the exit of the slit. These vortices have been studied and the graphical solutions of their equations of motion as a function of the peak pressure of the incident wave are presented. An equation is derived to enable the growth of the vortex to be found as a function of time and the peak pressure of the incident wave.

14. Experimental Study of the Formation of a Vortex Ring.* F. K. Elder, Jr. and N. de Haas, *Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland.*—The formation of a vortex ring at the open end of a cylindrical shock tube at the emergence of the shock wave was investigated by means of spark schlieren photography, using an electronic timing control. The shock tube was of a conventional type, having a constant inner diameter of 3.375 inches. The expansion chamber, open to the atmosphere, was a little over seven times the length of the compression chamber, which was filled with superdry tank nitrogen. Vortex-ring formation was investigated at two values of compression-chamber (gauge) pressure: 10 and 40 pounds per square inch. At these pressures the air jet is subsonic, and the contact surface does not reach the open end of the tube. Measurements of position as a function of time indicate that in the first millisecond after shock emergence the vortex ring accelerates from zero axial velocity to about three-quarters the theoretical particle velocity of the mass flow following the initial plane shock. The diameter of the vortex ring increases nonlinearly with time and distance.

* This work was supported by the U. S. Navy, Bureau of Ordnance.

15. Compressible Laminar Boundary Layers.* S. H. Christensen, *Georgia Institute of Technology.*—Assuming constant specific heat, unity Prandtl number and thermally insulated boundaries, the compressible laminar boundary-layer equations, under a Mises transformation and Mises independent variable, reduce to an equation analogous to the heat-conduction equation with variable "radiation" and "conductivity." A further change in independent variable removes the "radiation" term and the resulting equation is equivalent to the boundary-layer equations of an incompressible fluid having the same coordinate parallel to the surface as the compressible case, but a stretched normal coordinate, and variable viscosity which depends only upon the free-stream velocity. Further substitution of a stretched surface coordinate, related to the compressible coordinate by the free-stream velocity, results in the constant viscosity, incompressible boundary-layer equations. A similar transformation for the incompressible, constant viscosity case was found independently by Illingworth[1] and Stewartson,[2] using other methods of derivation. Variable viscosity method is simpler, however, and was applied to extend methods of Karman-Pohlhausen,[3] Goldstein[4] and Luckert[5] to the compressible case. Dimensionless curves of velocity and temperature profiles in the compressible wake behind an infinitely thin flat plate, from the trailing edge to two plate lengths down-stream, were obtained for free-stream Mach numbers of 0 to 10.

* Doctoral dissertation, Faculty of Arts and Sciences, Harvard University December 1, 1950.

[1] C. R. Illingworth, Proc. Roy. Soc. (London) **A199**, 533 (1949).

[2] K. Stewartson, Proc. Roy. Soc. (London) **A200**, 84 (1949).

[3] T. von Karman, Z.A.M.M. **1**, 233 (1921). K. Pohlhausen, Z.A.M.M. **1**, 252 (1921).

[4] S. Goldstein, Proc. Cambridge Phil. Soc. **26**, 1 (1930).

[5] H. J. Luckert, Schrift. d. Math. Seminars u.d. Inst. f.A. Math. d. Univ. Berlin **1**, 245 (1933).

16. Turbulent Heat Transfer for Flow in a Channel. Eugene N. Parker, *University of Utah.*—The field equations describing the spectrum functions of a turbulent flow in a channel are set up and an approximate solution is obtained. From the resulting spectrum functions one computes the increase of the effective viscosity due to the turbulence, and the increased pressure gradient needed to maintain the laminar flow. The enhanced heat transfer with the walls of the channel is also computed, giving a relation between the increased effective thermal conductivity and the Reynold's number of the flow.

17. Effects of Damping Screens and Stream Contraction on Turbulence. Maurice Tucker, *NACA Cleveland.* (Introduced by J. C. Evvard).—An analysis is presented of the combined effect of cascaded damping screens followed by an axisymmetric stream contraction (or expansion) upon the intensities, macroscales, and one-dimensional spectra of a triple Fourier integral representation of a turbulence field convected by a main stream. The treatment is restricted to negligible turbulence decay and linearized by postulating small turbulence velocity fluctuations and absence of viscosity except as simulated by the idealized screen action. Compressibility of the main stream is allowed for during passage through the contraction. The density fluctuations ordinarily associated with turbulence are regarded as negligible. Numerical results for the longitudinal and lateral intensities, scales, and spectra of turbulence downstream of a screen-contraction configuration are obtained for the case of initial isotropic turbulence. The action of damping screens and contraction is to distort this initially isotropic field into a field of turbulence symmetric about the longitudinal direction with the lateral velocity fluctuations greater in magnitude than the longitudinal. The use of multiple screens tends to equalize the lateral and longitudinal fluctuations. Allowing for decay effects by an approximation strictly suitable only for isotropic turbulence, the predicted intensities show a fair agreement with the experimental data of Dryden and Schubauer.

18. Luminous Effects in the Shock Tube. R. N. Hollyer, Jr., A. C. Hunting, Otto Laporte, E. H. Schwarcz, and E. B. Turner, *University of Michigan.*—Recent experiments by R. W. Perry and A. Kantrowitz[1] on converging cylindrical shock waves and by R. G. Fowler, J. S. Goldstein and B. E. Clotfelter[2] on shock waves in electric discharge tubes have directed attention to luminous effects in shock tubes. Such effects have been observed with the University of Michigan shock tube (2×7-inch cross section) several times in the past and it was decided to investigate these effects in more detail. Considerable luminosity is observed visually behind the reflected shock in the following: N_2, He, A, air and at incident shock strengths as low as $\xi=0.1$ and up to $\xi=0.03$. The investigation is being continued in two directions: (a) by the use of a wave speed camera it has been definitely established that the luminosity is in the extremely hot flow bounded by the reflected shock and later by the cold front, and (b) by spectrographic investigation using a two-prism glass spectrograph, identification of numerous lines between 6700A and 3500A is in progress.

[1] R. W. Perry and Arthur Kantrowitz, J. Appl. Phys. **22**, 878 (1951).
[2] R. G. Fowler, J. S. Goldstein, and B. E. Clotfelter, Phys. Rev. **82**, 879 (1951).

19. Observations on the Luminescence Accompanying Cone-Cylindrical and Spherical Missiles Traveling at High Speeds. J. Eckerman and R. N. Schwartz, *Naval Ordnance Laboratory, Silver Spring, Maryland.*—Open-shutter photographs and spectrograms have been obtained for 90° cone-cylindrical and spherical missles after traveling a path of from 50 to 100 calibers length in diatomic bromine and monatomic xenon. Observations were carried out with pressures varying from one to 200 mm of Hg. The missles had velocities of about 6000 ft/sec which gave a Mach number of 13 in bromine and 10 in xenon. An open-shutter camera using panchromatic film was focused on the missile path. The width of and intensity of the image increased in a regular manner with the density, reaching a maximum width of about one caliber. Information as to mechanism of light production was gained from density dependence of the luminosity. Although the cone-cylinders had a side and front survace area of about 2.8 times that of the spheres, about three times the gas pressure was required to produce the same light intensity. From the photographs and spectra taken, it was inferred that the major portion of the luminosity originated in the atmospheric gas. These studies were augmented by rotating mirror pictures.

20. Time-Resolved Spectroscopy of the Incandescence Associated with Ultra-Speed Pellets. Earle B. Mayfield, *Michelson Laboratory, U. S. Naval Ordnance Test Station, Inyokern, China Lake, California.* (Introduced by J. S. Rinehart).—Further results of work reported at the December 27, 28, and 29, 1951 meeting of the American Physical Society at Berkeley[1] have been obtained. Small, aluminum pellets have been fired at velocities of 15,000 ft/sec in a vacuum as well as in air at atmospheric pressure, and in Oxygen and argon at atmospheric pressure. These pellets have also been fired together in a 4′ glass tube with the same gases and in vacuum. In air, AlO bands are formed about 150 μ sec behind the pellet; in oxygen they are formed immediately. In argon, the lines of both aluminum and argon are excited. The pellets emit a continuum after colliding which persists for about 25 μ sec. In this region the Al lines at $\lambda\lambda$ 3944 and 3961 were reversed for the case of oxygen.

[1] Phys. Rev. **85**, 769 (1952).

21. A Qualitative Comparison of Meteor and Fast-Particle Spectra.* William C. White and Richard N. Thomas, *University of Utah and Naval Ordnance Test Station.*—Meteors have kinetic energies ranging from 3 to 530 ev per atom (in a center-of-gravity system with an atmospheric atom), and a metallic line spectrum corresponding to excited levels ranging up to 9 ev. 5–6 km/sec fast particles have kinetic energies ranging from 0.66 to 2.6 ev, and a spectrum containing metallic lines corresponding to excited levels ranging up to 5.9 ev. The fast particles must produce a region of high kinetic temperature, while current thought holds that the majority of meteors do not. A comment is presented on the number of similarities in type spectra produced, and its interest in view of the above characteristics. The utility of such comparisons in studying the mechanism of production of such spectra by atom-atom collisions is discussed.

* Work supported by Armament and Mechanics Branches, ONR.

22. A Semi-Quantitative Interpretation of an Al Fast-Particle Spectrum.* Richard N. Thomas and William C. White, *University of Utah and Naval Ordnance Test Station.*—An interpretation of the 5 km/sec aluminum pellet time-resolved spectra reported by Allen, Mayfield, Rinehart, and White is presented. The differential appearance time of 3.1 ev Al lines (earlier) and AlO bands (later) suggests two alteratives for interpretation—as a pure rate process with appreciable activation time for the AlO or as a sequence of quasi-equilibrium states. Calculations under the two assumed mechanisms appear to favor the latter interpretation as the predominant factor, although some activation effect cannot be excluded. A phenomenological discussion based on the conditions determining the kinetic temperature along the pellet trail seems to offer promise both in interpreting the current—rather incomplete—observations and in providing predictions on the behavior at higher velocities.

* Work suported by Armament and Mechanics Branches, ONR.

23. The Interaction of Plane Shock Waves and Rough Surfaces. Russell E. Duff, *Los Alamos Scientific Laboratory.*—Shock retardation in nitrogen was measured in a shock tube for a series of two and three dimensionally rough surfaces at shock strengths from $\xi=0.1$ to $\xi=0.9$ to determine the effect of a rough surface on a shock wave. The approximation was made that the volume between the positions of the shock wave with and without the rough surface present multiplied by the specific energy behind the shock wave represented energy dissipated by the roughness. The space rate of energy dissipation is presented as a function of the average particle size of the rough surface. It is also shown that the curvature of the shock wave in the vicinity of the surface depends on the roughness of the surface, the length of roughness covered, and the shock strength. The hundreds of measurements of shock wave contours made in this investigation showed that there is a random fluctuation in the angle of incidence of the primary shock wave of 1/15°. This fluctuation is presumably caused by the details of the diaphragm rupture even though measurements were made 14 ft from the diaphragm in a 2-inch by 7-inch shock tube.

24. Effects of Curved Shock Waves in Pseudo-Stationary Flows. C. H. Fletcher and A. H. Taub, *University of Illinois.*—Pseudo-stationary flows are those flows in which the flow variables (velocity, pressure, entropy, etc.) are functions of the independent variables x/t, y/t, z/t instead of the more usual x, y, z, and t. A necessary condition for pseudo-stationary flows is that the flow boundaries be describable in terms of the variables x/t, etc. in some inertial system for some choice of $t=0$. In the case of the interaction of a plane shock wave traveling along a wall and meeting an angle in the wall, the physical boundaries satisfy the necessary condition above and experiments indicate that the shock boundaries do also. T. Y. Thomas[1] has studied the curvature of a stationary (two-dimensional) shock wave in a uniform flow and its relation to the curvature of the streamlines in the flow behind the curved shock. An analysis along similar lines has been carried out for pseudo-stationary shock waves. The resulting relations are identical in some respects with those obtained by Thomas. The influence of these considerations on the theory of regular (two shock) reflection and Mach (three shock) reflection is pointed out.

[1] T. Y. Thomas, J. Math. Phys. **28**, 91 (1949).

25. Reflection of Shock Waves as a Pseudo-Stationary Phenomenon. A. H. Taub and C. H. Fletcher, *University of Illinois.*—The usual situation in the regular reflection of shock waves involves a reflected shock which is straight for a portion of its length near the intersection with the incident shock and is curved at some distance from this point. The conditions at the point where the reflected shock ceases to be linear are investigated along the lines suggested in the preceding abstract. It is shown that a continuous wave must also appear at this point. The form of this wave is restricted by the pseudo-stationary character of the phenomenon. Analogous reasoning is applied to the case of Mach reflection of weak shock waves near glancing incidence. The case is examined in which the curved Mach shock joins the straight incident shock with a continuous tangent and the conditions on the curvature of the Mach shock are examined.

26. Experimental Study of Shock Refraction.* R. G. STONER, E. B. DAVIES, AND C. L. WOODBRIDGE, *The Pennsylvania State College.*—The interaction of plane shocks at a plane interface between two gases has been studied at angles of incidence, α, up to 70° and pressure ratios $\xi(\equiv P_0/P)\geq 0.60$, using spark shadow photography. For certain ranges of α and ξ, a three-shock configuration[1,2] is observed. Application of oblique shock theory allows conditions behind the reflected and transmitted shocks to be calculated from their observed positions. Discrepancies in pressure and flow direction across the interface are attributable to the finite mass of the film which forms the interface. With air/CO_2, the reflected shock disappears when the angle of incidence approaches that for which the flow behind the incident shock becomes sonic. The situation is complicated by the catch-up of the signal from the corner, which is observed at about the same angle. With air/H_2, the three-shock configuration is replaced, beyond the angle for which the transmitted shock becomes normal to the interface, by a configuration similar to that previously described,[3] in which the transmitted wave runs ahead in the second medium and propagates a signal back into the first medium ahead of the incident shock.

* Supported by contract with ONR.

[1] A. H. Taub, Phys. Rev. **72**, 51 (1947).

[2] H. Polachek and R. J. Seeger, Phys. Rev. **84**, 922 (1951).

[3] R. G. Stoner and M. H. Glauberman, Phys. Rev. **76**, 882A (1949).

27. Measurement of Transient Flow Variables as a Function of Time.* C. W. CURTIS, R. J. EMRICH, AND J. E. MACK, *Lehigh University.*—Specification of a one-dimensional transient flow requires that the dependence of flow variables on both position and time be known. The required information can be obtained by recording changes in the flow either over the space of interest at successive times, or over the time of interest at successive positions. The chrono-interferometer to be described provides a record of the second type. The time interval over which this instrument can record is virtually unlimited, whereas the field of view of spatial interferometers is restricted by the size of available optical elements. Furthermore, since only small apertures are required, the chrono-interferometer is comparatively simple and inexpensive to construct. In the instrument constructed, the beam in one arm of a Michelson interferometer crosses a shock tube, and combines with the beam in the outside arm to give a single fringe in a $\frac{1}{8}$-in. diameter field. The resultant intensity is recorded photoelectrically on an oscillograph. The fringe count from the record yields an absolute measurement of the density change; fractional fringe shifts can be noted. The chrono-interferometer can be used to calibrate other devices recording in time such as piezoelectric and pressure bar gauges.

* Supported by the ONR.

28. On the Hydrodynamic Stability of Laminar Flame Fronts.* MARTIN LESSEN, *The Pennsylvania State College.*—In references 1 and 2, the stability of a laminar flame front to two-dimensional disturbances time variable is investigated. In reference 1, the flame front is considered as a discontinuity in velocity whereas in reference 2, a continuous distribution of velocity in the direction of flow is considered. In both works, the effect of energy dissipation is neglected. Both works conclude that the flow is unstable. In the present work, a dissipative flow is considered along with a three-dimensional disturbance. In a manner similar to that of reference 3, a transformation is found that transforms the three-dimensional disturbance equations to corresponding two-dimensional disturbance equations. The conclusions from the above are that if a minimum Reynolds number for stability of laminar flame fronts (based on flame front thickness) exists, it is the same for two and three dimensional disturbances. Hence, it is sufficient to consider only two-dimensional disturbances. It is also probable that such a minimum Reynolds number exists.

* This work was carried out at The Pennsylvania State College under ONR Contract NONR-656 (01).

[1] L. Landau, Acta Physicochim. U.R.S.S. **19**, 77 (1944).

[2] H. Einbinder, Phys. Rev. **75**, 1313 (1949).

[3] H. B. Squire, Proc. Roy. Soc. (London) **A142**, 621 (1933).

29. Compressible Fow of a Viscous Fluid in a Small Diameter Tube Closed at One End. J. M. KENDALL, *U. S. Naval Ordnance Laboratory.*—The basic nonlinear differential equation for a compressible viscous fluid flowing isothermally through a small diameter tube has been examined under the condition of nonslip. Under the assumption that the square of the pressure gradient is small compared to the rate of change of pressure gradient, the equation of pressure as a function of x and t takes on the form of the one-dimensional heat conduction equation (or also of the form of the voltage conduction in the long noninductive electric telegraph cable). Measurements were made of the pressure as a function of time at the end of a tube one and one-half millimeters inside diameter and fifteen-meters long as the pressure at the other end was suddenly changed by one quarter of a millimeter of Hg (10 percent change in initial pressure). The measured pressures as a function of time were in good agreement with those calculated using the solution of the corresponding problem of the temperature distribution in a bar.

30. Oscillations of the Gas Bubble Produced by an Underwater Explosion. L. C. BARRETT AND C. J. THORNE, *University of Utah.*—Under the usual assumptions, a derivation is given of the nonlinear differential equation governing the oscillations of the gas bubble produced by an underwater explosion. An integral solution of the equation is also obtained. Variations in the radius-time curve due to alterations in the gas constant γ are discussed, it being shown that neglecting the potential energy of the gas bubble leads to the same radius-time curve as that obtained by letting γ become infinite. This curve most nearly approximates the experimental data, over the contraction phase of the first cycle. A method of energy change is postulated which has the effect, on the integral solution of the differential equation, of replacing the constant coefficient appearing in the term representing the potential energy of the gas by a function of the radius, which, for a given γ can be numerically determined so that the experimental and theoretical curves coincide. A general procedure for determining the radius-time curve corresponding to any value of γ, or any temperature-independent equation of state, is also set forth, specific examples being carried through to illustrate the method.