FLUID DYNAMICS

A Conference Report

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ON the three days preceding Thanksgiving 250 physicists and other scientists met at Lehigh University to talk over their work in fundamental fluid dynamics. The occasion was the Tenth Anniversary Meeting of the Division of Fluid Dynamics of the American Physical Society.

Although there are several organizations of scientists and engineers which hold meetings to discuss general or specific aspects of fluid dynamics, the opportunity to concentrate on basic problems has attracted increasing numbers of scientists to the Physical Society organization. Sixty contributed and invited papers were presented during these three days on a wide variety of subjects.

On Monday morning, Lehigh's physicist-president, Martin D. Whitaker, welcomed the group. Then Raymond J. Seeger, one of those who organized the Division of Fluid Dynamics ten years ago, and the first chairman of the Division, recalled the part that the study of fluids in motion has played in the development of physical ideas. He remarked on the utilization of the fluid concept generally in physics, as in heat and electricity, but emphasized that real fluids are themselves a subject for continued interest.

Readers who are not themselves occupied in research in fluids may be interested to learn what subjects occupy the attention of specialists in this area of physics which today's physics textbooks generally leave at its nineteenth-century stage of development. In violation of the fact that the unifying theme of the meeting—matter in motion—was more evident than diversity of subjects, I have attempted to categorize the problems discussed at this meeting into a few subjects whose frontiers are being actively extended.

MECHANICS (32 of the 60 papers). There is a ubiquitous instability in fluid flows. Just as sea waves form white caps, compression waves grow into shock waves, laminar flows become turbulent, and pinched plasmas buckle or undulate out of the tracks set up for them. We want to predict the occurrence of such instabilities, we want to devise ways of deferring them, and we want to find what the fluids do in searching for more stable states of flow.

The inverted pendulum whose fulcrum is moved back and forth with the proper frequency will remain upright; in his talk, E. A. Frieman described a principle analogous to the one used to treat this problem which can be applied to a magnetofluid to test whether induced oscillations in the flow will lead to stability. H. D. Greyber and others discussed specific magnetofluid stability problems. Four papers treated the stability of fluids without magnetic interactions.

The largest area of interest in this category was in the description of the turbulent flows. Highly developed statistical descriptions of isotropic turbulence are suspected of inadequacies by R. H. Kraichnan who presented another formulation he finds more in agreement with experiment. H. L. Grant, of the Cavendish Laboratory in England, described experiments which show that turbulent motions have regularity and nonisotropy which currently developed statistical theories of isotropic turbulence cannot adequately describe. R. G. Deissler has extended a result showing isotropic turbulent energy is lost to viscosity at a rate proportional to $(\text{time})^{-5/2}$ at long times after the turbulence is created; his extension is to shorter times where the rate is proportional to $(\text{time})^{-7}$, and this is in agreement with experiments measuring the amounts of turbulent energy. Methods of studying transient turbulent boundary layers on the walls of a shock tube were described in two papers. A. J. Chabai, in studying the extent of laminar flow behind the shock, seems to find that each bit of gas set in motion by the shock carries with it the seeds of its own "downfall" into turbulence. G. Charatis and T. D. Wilkerson make the gas (neon) behind a fairly strong shock self-luminous by adding a little methane, and observe intense radiation when the hot gas in the middle of the tube mixes with the cold gas next to the wall.

Within the category of mechanics, but not directly concerned with flow instabilities, were many other interesting papers. Three authors pointed out the practicability of "insulating" high-temperature gases from solid surfaces by means of magnetic fields. Such high-temperature gases are present in hypersonic flows about satellite re-entry vehicles and in experimental fusion reactors.

Liquid helium in the superfluid state is so nonviscous and incompressible that it closely approximates the ideal fluid mathematicians have long assumed to permit analytic solutions of flow problems. J. M. Reynolds, B. J. Good, and W. J. Shultis described an experiment with a torsion pendulum in helium below 1.5°K which

Joseph Kaplan, chairman of the US National Committee for the International Geophysical Year, and Otto Laporte of the University of Michigan were among those present at the conference on fluid dynamics.

Arthur Kantrowitz, director of the Avco Research Laboratory at Everett, Mass., and a former chairman of the APS Division of Fluid Dynamics, confers with Walter M. Elsasser of Scripps Institution of Oceanography, who is currently vice chairman of the Division.

From left to right: R. J. Emrich, secretary-treasurer of the Division of Fluid Dynamics and the author of the present report; M. D. Whitaker, president of Lehigh University, where the conference was held; and F. N. Frenkiel, chairman of the Division and editor of *The Physics of Fluids*, a journal established earlier this year by the American Institute of Physics.

is satisfactorily explained in terms of the additional "apparent mass"—an effect derived mathematically many years ago by Stokes but never satisfactorily illustrated in ordinary fluids.

Although compression waves are unstable and end up as shock waves, a fruitful area of study in fluid dynamics has been the shock-wave behavior itself; it has many stable properties. But a thorn in the side of shock-wave students has been the inadequacy of the von Neumann and Taub triple-shock intersection theory to describe adequately some experimental facts observed in Mach reflections in shock tubes by L. G. Smith, W. Bleakney, and others. J. Sternberg described a theoretical approach which involves "looking inside" the shock waves near the triple-point intersection. This approach indicates that flow through the shocks cannot be described just in terms of discontinuities in flow variables at four surfaces (three shocks and a slipstream), but that a sort of rotation of the gas is introduced near the triple point. An interesting effect in a "resonance tube" was described by T. Vrebalovich. A cylindrical tube closed at one end and with its mouth open to oncoming supersonic air contains a resonating air column. The base of the tube gets hotter than the free-stream stagnation temperature (this is the maximum temperature the free-stream gas can attain by simply being brought to rest). The reason for the higher temperature in the "resonance tube" is that the air which remains in the tube has its entropy increased on succeeding cycles by shock waves which are part of the oscillating flow pattern inside the tube. Four other papers discussed flow fields containing shocks.

PROPERTIES OF MATTER (10 of the 60 papers). Arbitrarily excluding chemical reactions from this category, I have grouped kinetic theory, rarefied gases, high pressures, optical radiation, and conductivity studies performed in connection with flow processes.

Structure of a shock wave at the leading edge of a plate and of the boundary layer on the plate were studied experimentally by J. A. Laurmann under conditions where the mean free path of the gas molecules is comparable to the dimensions over which measurements were taken. At low densities the shock and boundary layer are not distinct near the leading edge, but emerge farther downstream. L. Marton, D. C. Schubert, and S. R. Mielczarek described methods using focused electron beams in strict analogy to optical schlieren for observing gas flows at pressures below 10^{-4} mm Hg.

The conductivity of an ionized gas will be employed to add energy by an electrodeless discharge to a supersonic air stream which has expanded through a nozzle. R. L. Chuan proposes to prevent large losses to the walls of the duct containing this air by using a 1000-gauss magnetic field to contain the hot, ionized, flowing gas. R. G. Jahn and D. K. Weimer outlined shock-tube experiments which produced a zone of partially ionized nitrogen behind a reflected shock. The free charge in this zone was found to be surprisingly mobile and able to penetrate the cold boundary layers on the walls of the tube.

Some normally solid substances are found to behave more like high-density fluids when subjected to extremely high pressures. Such conditions can be attained in metal plates in direct contact with detonating explosives, for example. Phase transitions in alkali halides, phosphorus, and bismuth are observed by measuring simultaneously shock-wave speeds and material speeds. A range of pressures (kilobars) considerable in excess of the static pressures employed by Bridgman is available for study, but only for very short times. Speeds in these experiments are measured in millimeters per microsecond. R. E. Duff and F. S. Minshall described experiments on bismuth which suggest that recrystallization takes place in less than one microsecond after the pressure is released. R. H. Christian and B. J. Alder observed that the recrystallization in phosphorus occurs in less than 0.1 microsecond; this phase change is permanent. This is a field of study equally interesting to the Division of Solid-State Physics.

HIGH-SPEED CHEMISTRY (16 of the 60 papers). This very active subject draws its current interest from the fact that extremely high temperatures can be attained behind strong shock waves in gases. Detonation waves in explosives involve similar high-speed reactions but the number of chemical species in these cases is large. More interest centers at the moment on vibrational equilibration, dissociation, and ionization of relatively simple gases.

A. Kantrowitz summarized the phenomena which can be expected to take place in the flow behind the bow shock at the head of a re-entry vehicle traveling with satellite speed. Nearly all oxygen molecules are dissociated into atoms, half the nitrogen is dissociated, and an appreciable fraction of the atoms and molecules is ionized. The temperature of this gas—if it is in equilibrium—is of the order of 10 000°K. Heat transfer to solid surfaces from a gas having these properties has been studied, using shock-tube methods; heat-transfer rates of the order of 10 kilowatts/cm^2 have been measured using fast-response resistance thermometers on the solid surfaces. Preliminary indications are that heat transfer by electromagnetic radiation is not as great as the transfer by fluid contact; at speeds higher than satellite speeds, however, the radiative transfer becomes an appreciable fraction of the total heat transfer.

The pioneer interferometric measurements by Blackman of vibrational relaxation rates in shock-energized nitrogen are being extended to oxygen where the dissociation relaxation times are much shorter (about 1/10 microsecond) and therefore more difficult to measure. D. L. Matthews reported observation of relaxation in O_2 dissociation behind a shock of Mach 10 in relatively high density (10 cm Hg) gas. Vibrational relaxation occurs even more rapidly than dissociational relaxation. M. Camac and C. Petty measured relaxation of O_2 dissociation and vibration in a mixture with argon by an ultraviolet absorption technique; use of argon as a diluent results in a higher temperature behind the shock, and argon-oxygen collisions are less effective in transferring energy to oxygen molecules than are oxygen-oxygen collisions, so the reaction proceeds but takes place more slowly than in pure O_2. W. H. Wurster and C. E. Treanor described shock-tube experiments indicating that both emission and absorption of light can be expected to be useful for identifying the chemical composition of air at temperatures of about 6000°K.

Peter P. Wegener, after reviewing several modern fluid-dynamic methods that have been applied to the study of chemical kinetics of fast reactions, described a new technique involving a continuously operating supersonic nozzle. This method was employed successfully to measure the rate constant of recombination of nitrogen dioxide into tetroxide directly. Also, shock waves produced in the test section of this small wind tunnel further permitted the study of the rate constant of dissociation. Of interest to the fluid dynamicist is the fact that this experimental arrangement represented a stationary supersonic-flow system with two participating species nowhere in chemical equilibrium.

The hydrogen-oxygen detonation is a complicated flow problem that is beginning to yield to analysis by shock-tube and optical techniques. H. T. Knight and R. E. Duff employ flash x-ray absorption methods, and D. R. White is using an interferometer in the "detonation tube". It is now clear that a shock can pass through an explosive mixture and raise its temperature considerably without "igniting" the chemical reaction. The reaction starts somewhere behind the shock, perhaps in the boundary layer on the tube walls. Once the reaction starts, probably at several points or nuclei, it proceeds at surfaces (flame fronts) which grow outward to meet and form cells. The burning has raised the pressure in the medium and results in compression waves which overtake and strengthen the initial shock. Eventually a stable shock and burning zone is attained, but this seems to be difficult to achieve in practical sizes of tubes.

SIXTY papers in three days constituted a heavy bill of intellectual fare; the equations were set aside for a while on Tuesday night for a Pennsylvania Dutch dinner—the Tenth Anniversary Banquet of the Division—and for remarks by F. N. Frenkiel and Joseph Kaplan on the role fluid dynamicists and other scientists could and should play in our national society. Two needs were stressed: the need for greater public awareness of the nature of fundamental research and the need for increased public support for the training of scientists to carry on fundamental research. Frenkiel suggested that the respect due one's parents, clergyman, and teachers in a healthy society was lacking in its balance in our country today; the prestige of the teacher should be restored. Kaplan remarked on how hard it is for the public, even as represented in Congress, to grasp the meaning of science and the aims of science. Although sometimes it might seem desirable to scientists to have Newton's Laws of Motion read into the Congressional Record, Kaplan felt that even if this were done evidence in less abstract terms would still be needed to clarify the need for support of basic research and to explain what "supports" the satellite out there. Kaplan, who is chairman of the U. S. National Committee for the International Geophysical Year, then outlined for the group the large part the physics of fluids plays in the International Geophysical Year.

The establishment of the new journal *The Physics of Fluids* published by the American Institute of Physics with F. N. Frenkiel as editor was announced at the meeting. *The Physics of Fluids* will publish papers in a wider range of subjects than that encompassed in the usual meaning of fluid dynamics. The vigor and variety of research described at this meeting indicate that the new journal will be advantageously used.