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Letters to the Editor

LETTERS to the Editor include two sections: Research Notes and Comments and Errata. Communications published in these sections should not exceed 1000 words in length including the space allowed for figures and tables. Research notes include important research results of a preliminary nature which are of special interest to physics of fluids and new research contributions modifying or improving results published earlier in the scientific literature. Comments and Errata refer to papers published in The Physics of Fluids. *The Board of Editors will not hold itself responsible for the opinions expressed in the Letters to the Editor.*

Research Notes

Response of Electrostatic Probes to Ionized Gas Flows in a Shock Tube*

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IN HIS excellent analysis of electrical measurements in shock tube flows, Hollyer[1] has demonstrated certain pitfalls in the application of conventional Langmuir probe techniques to the evaluation of charge densities in the moving stream of hot gas confined within the tube walls. The purpose of this note is to describe somewhat similar experiments which illustrate other eccentricities in probe behavior under these conditions. Two platinum films, each about 3 mm wide are painted 3 cm apart on the inner wall of a 3.5-cm i.d. Pyrex shock tube section (Fig. 1). The head-on reflection of a Mach 6 shock in nitrogen, initially at 5-mm Hg pressure, is allowed to pass over the two films in succession, and the response of the first film only is recorded on a Tektronix 535 oscilloscope. As shown in Fig. 2, the signal developed on passage of the shock front and the ionized gas behind it is strongly dependent on the load resistance R_L connecting the films to ground. If R_L is small, $\sim$1000 Ω, the first film records two different types of positive signal: a small sharp pulse on passage of the shock front over itself, and a larger, noisy signal upon passage of the front over the second, nonrecording film [Fig. 2(a)]. If R_L is made very large, $\sim 10^6 \Omega$, the noisy, protracted signal disappears entirely and is replaced by a second sharp pulse, inverted with respect to the first and somewhat smaller than it, occurring again at the time of passage of the shock front over the second, nonrecording film [Fig. 2(b)]. For either value of R_L, if the response of the second film is recorded, rather than the first, the entire pattern is inverted and the first pulse is somewhat smaller [Fig. 2(c), (d)].

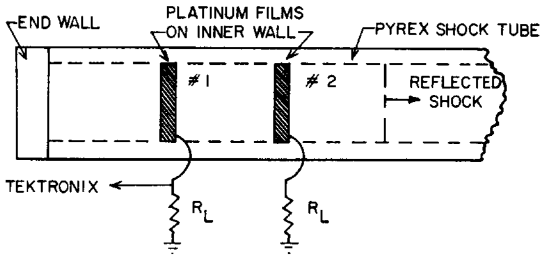

Fig. 1. Arrangement of two platinum film probes on inner wall of Pyrex shock tube (schematic).

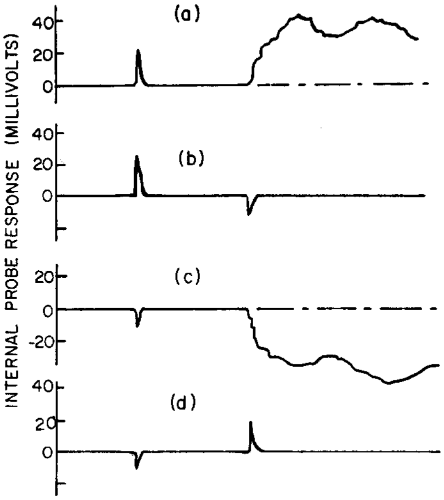

Fig. 2. Response of inner probes to passage of reflected shock. (a) Response of first probe, both $R_L \sim 1000\Omega$; (b) response of first probe, both $R_L \sim 10^6\Omega$; (c) response of second probe, both $R_L \sim 1000\Omega$; (d) response of second probe, both $R_L \sim 10^6\Omega$.

Sharp pulses of somewhat smaller amplitudes are detected by electrostatic probes mounted on the outside of the glass shock tube section, at times corresponding to the passage of the shock front over the internal films. These pulses, and hence some portion of the sharp pulses recorded by the films themselves, would thus seem to be electrostatic inductions generated by the interaction of the shock with the metallic strips. The mechanism of this is obscure; it may be that the abrupt exposure of the ionized gas behind the shock to a conducting path to ground momentarily disturbs its charge configuration, causing a signal to be induced on nearby detectors. If so, the induction is asymmetric, for the polarity of the pulses observed changes with the axial position of the detector relative to the grounding element. In particular, the response of the second internal film to the passage of the shock over the first, which presumably is the same inductive effect, is negative, while that of an external probe midway between the two films is positive.

The noisy protracted signals which are sensitive to R_L are not detectable outside the shock tube and would seem, therefore, to represent actual conduction of current from one film to the other through the ionized gas, despite the absence of an external driving potential.

We infer from these results that the configuration of the free charge in the transient flow generated by the shock is such as to establish internal potentials capable of inducing sizable electrostatic signals on remote detectors and likewise capable of driving currents from one probe to another. In addition, signals generated in one probe are mirrored in other nearby probes with little loss of amplitude. All such signals, then, will be superimposed on the usual probe response to the charge sheath configurations in their immediate neighborhood.

This, and other related experiments are described in detail in a technical report.[2]

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* Experiments performed at Lehigh University, supported in part by an Office of Naval Research contract.

[1] R. N. Hollyer, "Preliminary studies in the APL high temperature shock tube," Tech. Rept. No. CM-903, Applied Physics Laboratory, Johns Hopkins University.

[2] R. G. Jahn and F. A. Grosse, "A study of the processes induced by the reflection of strong shocks in nitrogen," Tech. Rept. No. 13, Physics Department, Lehigh University.

Cylindrical Shock Waves from Exploded Wires of Hydrogen-Charged Palladium

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THE geometry of the cylindrical wire explosion suggests an analogy with a shock tube of radial symmetry. In the analogy the expanding cylinder, presumably of metal vapor, corresponds to the expanding reservoir of compressed gas. The ambient atmosphere around the wire corresponds to the driven gas. If one considers an infinitesimal sector of the circular cross section, then for sufficiently small time intervals, phenomena within the sector near the shock may be assumed to proceed as in a conventional linear shock tube. Of course, over long time intervals the shock wave with cylindrical symmetry will decrease in strength and the flow behind it will be unsteady or at most only pseudostationary. For the production of strong, plane shock waves the work of Resler *et al.*[1] demonstrates the importance of a driver gas with high sound speed relative to that of the driven gas. With the perfect gas assumption, the ratio of these sound speeds is given by $a_4/a_1 = (\gamma_4 T_4 M_1/\gamma_1 T_1 M_4)^{\frac{1}{2}}$, where 4 refers to the driver and 1 to the driven gas. Symbols a, γ, T, and M represent sound speed, specific heat ratio, Kelvin temperature, and mass of gram-mole, respectively. For this ratio to be large, the preferred situation, the ratios T_4/T_1 amd M_1/M_4 should be separately as large as possible.

Recent work[2] has shown that exploding wires are capable of producing strong shock waves. One may infer that in these cases the ratio a_4/a_1 is comparatively large. The favorable element seems to be the ratio of temperatures, which can be large enough to satisfy the inequality $10 \leq T_4/T_1 < 100$. It is supposed that temperatures of the metal vapor as high as 6000°K may occur. On the other hand, the molecular weight ratio for metal wires in air is likely to be quite unfavorable. For example, copper relative to air gives a value $M_1/M_4 = 0.45$. Lighter metals can be selected, and should be examined experimentally from this point of view. The lightest known metal, *viz.*, lithium, yields a ratio $M_1/M_4 = 4$. The possibility of an even more favorable choice is seen to exist if one considers metals capable of occluding hydrogen, for example palladium. Solid palladium has the property of occluding hydrogen up to atomic ratios H/Pd $\leq$ 0.8.[3] Put another way this charge amounts to about 1000 volumes of molecular hydrogen at N.T.P. per volume of metal. Thus a charged Pd wire at room temperature is roughly equivalent to a reservoir of compressed hydrogen the same size as the wire but at 10^3 atmos pressure. If the gas can be rapidly heated to high temperature by the wire explosion, and if the hydrogen escapes and expands more rapidly than the metal vapor, than there is the possibility of strong shock formation in a configuration with cylindrical symmetry and with the most favorable sound velocity ratio it is presently possible to achieve. Streak pictures[4] from 5-mil Pd wires exploding into 1 atmos air have been obtained at 28 kv with a constant stored energy of 118 j in a circuit with a ringing time of about 2 μsec. A characteristic feature of these explosions is the wedge-shaped tip which depicts an initial luminous phase nearly linear with time. The shock wave presents a curious broken appearance and does not assume the expected parabolic shape until after 1 μsec has elapsed. The flashes are not quite as brilliant as those obtained with Cu wire; yet parabola test plots as described in [I][2] show the shock wave from the Pd wire to have an apparent axial energy release of 31 j/cm, a value somewhat larger than that for the 5-mil Cu wires. The cold resistance of the Pd wire is larger by a factor of about 6.5.

A 5-mil Pd wire was charged with hydrogen by electrolysis as the cathode in weak sulfuric acid solution. Precision potentiometer measurement of wire resistance before and after charging showed a stable resistance ratio a few percent larger than $R/R_0 = 1.7$ which indicates an atom ratio H/Pd $\geqq$ 0.8 from the charging curve given by Smith.[5] Samples of this wire when exploded gave non-backlighted streak pictures of which the most noticeable feature is a dark practically nonluminous, tip of some 2-μsec duration. Contrary to expectations the charged wire shows less luminosity and by inference a weaker shock wave than the uncharged wires. This behavior is understandable if one supposes that the hydrogen present in the wire escapes during the very early stages of electrical heating and is present, when the explosion occurs, as a gaseous envelope in the cylindrical shell just outside the wire. Under these circumstances the situation is the inverse of that favorable to strong shock production. When the wire explodes the shock wave can be formed presumably only by a heavy metal vapor driving a light gas. The ratio of sound velocities a_4/a_1 will be adversely affected by the unfavorable molecular weight ratio and only a weak shock could result unless the temperature ratio is unexpectedly high. The indication is clear that unless the hydrogen can be effectively retained in the wire, strong shock waves are not likely to be produced.

With the discovery that strong shock waves cannot be generated by unmodified Pd-H wires, presumably because the hydrogen escapes from the wire before the explosion occurs, means of sealing the hydrogen inside the wire have been sought and tested. The simplest solution to the problem seems to consist in selecting a metal relatively impermeable to hydrogen and plating a thin layer onto the fully charged Pd wire. The plated,