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PROBLEMS IN SHOCK WAVE RESEARCH

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I. HISTORICAL REVIEW

Theoretical studies of shock waves, their structure and their propagation date well back into the 19th century. Poisson, Stokes and Earnshaw were early pioneers; Rankine, the great Scottish engineer, and a less reknowned French scientist, H. Hugoniot, established foundations which were later elaborated by Rayleigh,[1] G. I. Taylor,[2] and P. Duhem.[3] Their work, along with more recent contributions by Bethe,[4] von Neuman,[5] Gilbarg,[6] R. Courant and K. O. Friedrichs[7] and others, has been adapted to solids in recent years[8] and serves us well today for most purposes. Recent developments by G. R. Fowles and R. Williams[9] promise a new dimension in the interpretation of experiments in solids, but fulfillment of their promise may await new measuring techniques.

Early experiments on the shock waves produced by projectiles in air were done by Ernst Mach,[10] who established a tradition for the use of high speed optics which has been carried on by Cranz and Schardin,[11] Walsh,[12] Fowles[13] and others. Consideration of the problems of supersonic aircraft gave impetus to the study of air shocks before and after WWII (Howarth[14]), and since 1950 there has been detailed and extensive study of shocks in gaseous plasmas.[15,16]

Modern developments in the study of shock waves in solids really arise from the Manhattan Project during World War II. Details of this period are lost in files of the Atomic Energy Commission and in the memories of various individuals. However, we do know that in this time and place it was realized that the jump conditions could be used to obtain pressure-volume relations, that experimental techniques for producing and measuring plane shock waves from explosives were developed, and that in the years following World War II a series of pioneering papers on this subject came out of Los Alamos.[12,17-19] Work done there also provided a frame and foundation for studies of elastic precursors and phase transitions, which have occupied so much of our energies during the last fifteen to eighteen years.

Progress in shock wave physics has been strongly tied to developments of experimental techniques. Los Alamos studies were initially largely made with pins used to record free surface motion. The use of these was highly developed by Stanley Minshall,[17] but they have been supplanted by flash gaps, initially developed by Walsh,[12] which are still widely used for pressure-volume measurements above 100 kbars. As interest developed in the detailed structure of shock waves, it also turned toward lower pressures and more refined recording methods. Optical level techniques developed by Fowles[13] and Doran[20] at Stanford Research Institute provided sensitivity for measurements at low pressures and quasi-continuous records of free surface motion. A condensor microphone method developed by Taylor and Rice of Los Alamos[71] offered significant improvement in time resolution, and an electromagnetic procedure used by Fritz and Morgan[72] has recently produced records of high resolution. Major steps forward were provided by Sandia Laboratories: first in Lundergan's development of the gas gun for impact studies[21,22] and then in development of the quartz gauge by Neilson, Benedick, Brooks, Graham and Anderson[23] and the laser interferometer by Lynn Barker.[24,25] These combined developments have led to resolution times of one to five nanoseconds in shock structure measurements below forty kilobars and to sharply enhanced abilities to evaluate theoretical models of material behavior. In a somewhat different class are the electromagnetic velocity gauge invented by E. K. Zavoiskii of the USSR[26] and the manganin gauge first developed by Keough and Bernstein at Stanford Research Institute.[27] These are gauges to be imbedded in a sample. They will probably never compete with quartz gauge and laser interferometer for time resolution, but they can be used to much higher pressures and can reduce problems of impedance mismatch. The potential of neither, nor of their various offspring, has yet been realized.

It has turned out that mechanical measurements yielding pressure-volume relations, precursor structure and phase transitions have been relatively easy to do. Electric, magnetic and optical measurements are much harder, though many have been done and some have been done well.[28] Still, the possibilities for research in this area are great, and, as mechanical measurements become harder, more attention will probably be directed toward these problems.

High speed computing machines play a particularly significant role in shock wave research. Without them one is constrained to consider shocks as discontinuities and to give minimum attention to details of shock structure between the discontinuities. Shock problems are relatively easy to solve numerically, and with high