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EMI Shock Tube Experiments

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Technical Report

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13. ABSTRACT *(Maximum 200 words)*

This work was undertaken to increase the understanding of the fluid dynamics of shock wave reflection phenomena. Parametric height-of-burst (HOB) experiments were performed to establish a consistent set of HOB peak overpressure curves in the low pressure regime (< 100 psi) for hydrodynamically smooth and rough surfaces. The laboratory technique used employed 0.5-g NP charges. Shock tube experiments were performed to study turbulent boundary layer effects behind shocks and mixing effects in boundary layers with different sound speeds. Precursor and "decursor" phenomena were studied.

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1.1 GENERAL REMARKS.

Research conducted during the contract period concentrated on the following topics:

1. Small-Scale HOB Tests
2. Shock Tube Experiments.

As the research progressed, it was determined that the most important work was the Small-Scale HOB Testing and DNA directed that efforts be concentrated in that area. The authors would like to recognize the significant contributions to this research made by Dr. Allen L. Kuhl, RDA. Dr. Kuhl also served as the conduit for information reported to DNA.

2.1 RESULTS AND CONCLUSIONS.

2.1.1 Small-Scale HOB Tests.

Under this contract, an extended series of parametric height-of-burst (HOB) experiments was performed to establish a consistent set of HOB peak overpressure curves in the low pressure regime (< 100 psi) for hydrodynamically smooth and rough surfaces. The results of these tests are documented in the following reports and papers:

a. EMI Report E 3/89
"HOB-Isolinien für Micro-Mach-Experimente auf rauher Oberfläche"--Datenreport
G. Scheklinski-Glück
H. Reichenbach

b. EMI Report T 1/90
"HOB Test Data With Smooth Surface (Macrolon)"
G. Scheklinski-Glück, EMI
H. Reichenbach, EMI

c. EMI Report E 7/90
"Reflection of Spherical Waves From Smooth Surfaces:
RR-MR Transition of Low Pressures"
H. Reichenbach, EMI
G. Scheklinski-Glück, EMI
A.L. Kuhl, RDA

d. EMI Report E 10/90
"Comparison of the HOB Curves for 0.5-g NP Charges With
Field Test Data"
H. Reichenbach, EMI
G. Scheklinski-Glück, EMI
A.L. Kuhl, RDA

e. "HOB Experiments with 0.5-g Charges"
Progress Report (June - December 1989)
A.L. Kuhl, RDA
H. Reichenbach, EMI
G. Scheklinski-Glück, EMI

f. "HOB Experiments with 0.5-g NP Charges"
H. Reichenbach, EMI
A.L. Kuhl, RDA
Presented at the Symposium on Military Applications of Blast Simulation (MABS), Albuquerque, NM (1989).

The laboratory technique used in the above publications employed 0.5-g NP charges. It is a very effective technique for studying blast wave reflections from various surfaces. The NP data agree with other data from large HE charges, but the NP data have less scatter and are more self-consistent. The NP HOB curves are the most accurate curves available today for overpressures in the range $2 \leq \Delta p$ (psi) ≤ 100. The knees in the HOB curves are reduced (relative to the von Neumann two-shock theory) in the low-pressure transition region--even for the case of a hydrodynamic smooth reflection plane. Roughness or porosity in the reflecting plane further erodes the knees in the HOB curves. Boundary layer effects on the HOB curves were estimated for the hydrodynamically smooth surface, and it was found that the deficit in ground range to the same overpressure increased logarithmically with range. Even after employing this boundary layer correction, the HOB curves remain below the two-shock theory curves in the low-pressure transition region.

We believe that boundary layer effects may cause the shock structure to transition to Mach reflection before the detachment angle is reached (theoretical limit of the existence of two-shock solutions). Also, boundary layer effects suppress the triple point trajectory just after transition and hence clip the very peaked waveforms observed in the low pressure transition region. These effects, along with gauge diameter limitations, are responsible for pulling the knees of the HOB curves in and down in the low pressure transition region.

We have now an extensive data base for reflections of spherical blast waves from surfaces. But in the low-pressure region (i.e., below 2 psi) the data are mostly extrapolated because the size of the explosion change is too small. We propose therefore to build a bigger chamber with overall dimensions of 2.5 x 1.8 x 1.2 m. Then we will be able to enlarge the capability of our experiments in a region where free-field measurements are extremely difficult due to weather and other surrounding conditions.

2.1.2 Shock Tube Program.

Shock tube experiments were performed to study physical phenomena especially in the boundary layer region. Examples of these experiments were studies of turbulent boundary layer effects behind shocks and mixing effects in boundary layers with different sound speeds. In the case of a layer with higher sound speed, a precursor shock was established, whereas in a low sound speed layer, a "decursor" was created. To study the decursor phenomena, new techniques had to be developed and extensive shock tube tests had to be performed.

a. Development of New Techniques

A new computer-controlled heating system was developed by EMI and successfully tested to perform a parametric series of precursor tests in a shock tube using the heated-foil technique. The rise time of the electric current used to heat the foil and the duration of the current were independently adjusted to study heating effects. Foil temperatures of more than 2000 K were reached.

Physical Research, Inc. (PRI) was placed under separate contract to DNA to develop diagnostics for the EMI shock tube. PRi developed a laser Doppler velocimeter (LDV) to measure gas velocities, laser attenuation (LAT) probes to measure gas concentration, and special computer software to analyze interference ring photography for density measurements. Extended experiments were performed in the EMI shock tube using the PRI diagnostics to test components for LDV measurements and also to check methods to measure the concentration of different gases in the boundary layer. Details of the LDV, interference fringe reduction software and concentration measurements are to be reported by PRI in their final report under DNA contract DNA001-89-C-0018.

b. Shock Tube Experiments

Extended tests were performed in the EMI shock tube to study the decursor phenomena. The decursor was formed by propagating a shock wave through a layered media where the layer near the surface had a lower sound speed. To produce such a layer, Freon-12 was injected through a Filtrokelit plate. The same apparatus was successfully used in the past to produce high sound speed He layers for precursor studies. Results of these tests are documented in:

Technical Note No. 3/89
"Turbulent, Dense-Gas Layer behind a Shock Wave"
H. Reichenbach, EMI
A.L. Kuhl, RDA.

The dense-gas layer is in some respects a simulation of a dusty boundary layer where the dust particles are represented by the heavy molecules of Freon-12. To enlarge the density ratio across the layer, Helium was used as ambient gas instead of air so that a density ratio of about $\rho_{Freon}/\rho_{Helium} \approx 30$ was realized. (Such density ratios are similar to those found in a fluidized dust bed of dusty boundary experiments in the TRW shock tube.) Therefore, one can expect that the dense-gas layer can simulate the inertial dynamics of dusty boundary layers for the case where the dust particles have a very small size, i.e., where the dust essentially is in velocity equilibrium with the gas. The advantage of this gasdynamic simulation of the dusty boundary layer is that it is amenable to gasdynamic measurements (stagnation pressure, optical visualization, LDV, etc.) which are considerably more difficult in two-phase flows.

The shadow photographs in our tests show the turbulent mixing process in the gas behind a shock wave. Coherent structures in the form of more or less periodic bubble-like areas were observed. The period seems to depend on Mach number and density ratio across the layer. But the test data have not yet been fully evaluated and the variation of the shock Mach number is not sufficient to be able to compare the density ratio effect at the same Mach number for different ambient gases.

We planned to measure the velocity profile and the RMS velocity fluctuations in the turbulent boundary layer (by PRI's LDV system) and the density profiles and fluctuations (by PRI concentration measurement technique). The PRI measurement systems were not delivered during our contract period. We will use the PRI systems on subsequent research.

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