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FINAL REPORT

ON THE

STUDY OF THE DYNAMICS OF EXPLOSIONS IN FUEL-AIR MIXTURES

RESEARCH PROGRAM SUPPORTED BY GRANT NO. AF-75-2772

October 1, 1976 - September 30, 1977

Introduction

The primary purpose of this research program was the acquisition of knowledge on unconfined explosions generated by fuel-air mixtures. This was deemed of interest to the Air Force both for reasons of safety associated with proper handling of fuels, as well as to provide the required scientific background for the design of novel explosive devices that would be capable of furnishing means for the destruction of the intended target without inflicting undue damage to the surroundings.

Specifically, upon the recognition of the fact that, in principle, explosions are generated by exothermic processes, the program of research was directed to provide fundamental information on the interrelationship between high rate reactions associated with heat release and the non-steady gasdynamic phenomena they produce. This lead to the following accomplishments: (1) the identification of prominent physical and chemical parameters governing explosion processes in fuel-air mixtures, (2) the development of computational models to analyze the initiation mechanism, and (3) the establishment of criteria for explosive ignition. In this connection, experiments were performed in shock tubes and explosion vessels, using appropriate hydrocarbon-oxygen mixtures. The gasdynamic phenomena of the non-steady flow fields under investigation were observed by means of high-speed schlieren and interferometer techniques, using pulsed ruby laser as a light source, in an optical system producing cinematographic records at a frequency of 500,000 frames per second.

Progress

In the experimental phase, a study on the effect of hydrogen on methane oxidation was completed. Experiments were performed in a shock tube, using the reflected shock technique. Ignition processes were observed by means of cinematographic laser schlieren and cinematographic laser-shear interferometry. Induction times and strong ignition limits were determined on the basis of wave front trajectories in the time-space domain, deduced from pressure records.

Test mixtures included two methane-oxygen mixtures, seven methane-hydrogen-oxygen mixtures and two hydrogen-oxygen mixtures all diluted by 90% argon. Initial conditions of the experimental runs were in the range of $300^{0}K$ - $2500^{0}K$ in temperature and 1.4 atm - 3.0 atm in pressure. The results are so far published in the form of a Ph. D. thesis (1).

In the analytical phase, self-similar solutions were obtained for blast waves with transport properties (2), and for explosion waves of variable energy at the front (3), as well as for a class of non-self-similar waves in real gases (4).

In the computational phase, detailed results on the structure of blast waves generated by exploding clouds were published in the form of a paper presented at the XI Shock Tube Symposium (5).

As a useful by-product, our program supported the development of an ultra-high-frequency (100 - 500 MHz) semi-conductor pressure transducer, which was realized by incorporating a thin layer (1.2 um) of a piezoelectric film (ZnO) into a field-effect (MOS) transistor (6).

Summary

New knowledge gained by our research effort is concerned primarily with progress in the understanding of explosion waves in gaseous media and their control. In essence, on the basis of an experimental study conducted over the period of October 1, 1976 to September 30, 1977, we were able to provide rational basis for the assessment of the influence of hydrogen on the explosion of methane, while, as a consequence of our analytical investigations, we elucidated a number of processes and properties affecting the the structure of blast waves; prominent among them were those of transport phenomena, of the power level at which energy can be deposited at the front, and of real gas effects. Moreover, we solved by numerical analysis, using

our CLOUD CODE, the problem of the structure of blast waves generated by exploding clouds, demonstrating that the question whether the cloud was consumed by detonation or deflagration is irrelevant provided that the burning speed is high enough (of an order of 30 m/sec) and one is interested in the destructive effects at least five cloud radii away from the ignition source.

Publications

1. "Induction Times and Strong Ignition Limits for Mixtures of Methane with Hydrogen," by R. K. Cheng, Ph. D. Thesis, 165 pp., University of California, Berkeley, June 1977.

2. "A Self-Similar Solution for Blast Waves with Transport Properties," (with M. M. Kamel, H. A. Khater, H. G. Siefien, and N. M. Rafat) Acta Astronautica, Vol. 4, Issue 3-4, pp. 425-437, March-April 1977.

3. "Self-Similar Explosion Waves of Variable Energy at the Front," (with G. I. Barenblatt, R. H. Guirguis, M. M. Kamel, A. L. Kuhl, and Ya. B. Zel'dovich) Journal of Fluid Mechanics.

4. "Blast Waves in Real Gases," (with M. M. Kamel, A. F. Ghoniem, and M. I. Rashed) Acta Astronautica, Vol. 4, Issue 3-4, pp. 439-458, March-April 1977.

5. "Blast Waves Generated by Exploding Clouds," (with J. Kurylo, L. M. Cohen, and M. M. Kamel) Proceedings of the XI International Symposium on Shock Tubes & Waves, University of Washington, Seattle, July 11-14, 1977.

6. "Detection of Acoustic Waves with a PI-DMOS Transducer," (K. W. Yeh, R. S. Muller, and S. H. Kwan) Japanese Journal of Applied Physics, Vol. 16, Supplement 16-1, pp. 517-521, 1977.