CONF-900756--50

UCRL--102576

DE91 000813

Uses of Fabry-Perot Velocimeters in Studies of High Explosives Detonation

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This paper was submitted to the SPIE's 1990
International Symposium on Optical and
Optoelectronic Applied Sciences Meeting
San Diego, Ca July 9-13, 1990

August 27, 1990

Received by OSTI
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INTRODUCTION

The Fabry Perot has become an important and valuable tool by which explosive performance information can be obtained relatively easily and inexpensively. Principle uses of the Fabry Perot have been free surface, and particle velocity measurements in one dimensional studies of explosive performance. In the cylinder test, it has been very useful to resolve early wall motions.

We have refined methods of characterizing new explosives i.e. equation of state, C-J pressure, via the cylinder shot, flat plate, and particle velocity techniques. All of these use Fabry Perot as one of the principle diagnostics. Each of these experimental techniques are discussed briefly and some of the results obtained. Modeling developed to fit Fabry-Perot results are described along with future testing.

EXPERIMENTAL

Nanosecond time resolution detonation studies can be routinely carried out with the use of Fabry-Perot. Previous researchers have used several techniques to study detonation flow. Hayes and Erickson [1,9] used thin gauges or foils sandwiched between layers of explosive. Large magnets were required to produce fields in which the foil position was driven by the detonation front. Manganin pressure gauges have also been used to obtain pressure versus time in explosives for some time as well as ultra-fast arrival pins which measure wave front velocities.

Using Fabry-Perot or VISAR laser interferometry one can measure velocity directly with a minimum disturbance to the detonation flow. It is a non contact method and records velocity directly and continually, not at time of arrival points as with pins. Experimental assembly is easily accomplished whereas other methods require precise and careful placement of wires or gauges within layers of explosive.

We have established a method whereby explosives can be very carefully characterized with only a dozen experiments using Fabry-Perot. They are the following:

- Duplicate cylinder experiments.
- Six head-on flat plate push experiments.
- Four particle velocity experiments.

FABRY PEROT SYSTEMS

We have several Fabry Perot systems available for explosive performance studies. A schematic layout of our present system is shown in Figure 1. Fabry systems were first installed into our Site 300 explosive firing bunkers. They have evolved to the present techniques of using laser amplifiers, fiber optics, and splitting the beams for recording two velocities from the same experiment.[2]

Fabry Perot velocimeters have also been used on large, 100mm diameter guns, which can accelerate projectiles over 2.0 mm/us. These Fabry systems usually look at the rear surfaces of explosives or metal plates which were impacted by a planer projectile.

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* Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livemore National Laboratory under contract No. W-7405-ENG-48.

An other Fabry Perot system has been built to support two separate shot tanks. Explosive capacity of one tank is 100 gms and the other is capable of firing 350 gms. One Fabry-Perot system supports either shot tank by simply moving a single mirror. Shots in these tanks are relatively small and inexpensive to conduct and several experiments can be done on a single day. An electric gun[10] is used to fire shots which reduces the amount of explosive in a tank. By using different flyer velocities and slapper thicknesses we can taylor impact conditions for ignition studies.

FREE SURFACE STUDIES

Thin metal plates are bonded to the top of the explosive and the acceleration of the plates is recorded with the Fabry- Perot. Shown in Figure 2 is a layout of typical shot assembly. We initially used copper to measure free surface velocities of explosives. The thicker, 0.5mm, copper plates spalled. Tantalum has been successfully used without spalling and continues to be our primary metal for free surface measurements.

We have standardized tantalum plate to explosive thickness as shown in Table 1. Specimens are 25.4 mm in diameter and weigh 5, 10, and 15 grams, respectively.

TABLE 1

Plate Thickness	HE Thickness
0.102 mm	6.0 mm
0.254	6.0
0.508	12.0

The 0.102 mm thick plate is thin enough that the reaction zone characteristically will accelerate the thin plate to a higher initial jump off and a much steeper pull-back than thicker plates.

PARTICLE VELOCITY MEASUREMENTS

A detonation front can be observed as it exits the explosive into a material of the same or very nearly the same impedance. By impedance matching, the structure of the front is undisturbed and can be observed. We have successfully used NaCl and LiF crystals to conduct these measurements. Shown in Figure 3 is a schematic of the experimental arrangement.

The crystals are coated with 4000 angstroms of gold on one surface. The explosive specimens are lapped flat to obtain intimate contact between the crystal and the explosive. The gold surface is put next to the explosive, the laser beam goes through the crystal and reflects off of the gold. Wackerle[3] has measured the index of refraction of several materials. The two crystals we are using have a constant correction over a large pressure range. A typical record is shown in Figure 4.

CYLINDER TESTS

The traditional cylinder test used only streak cameras to measure detonation product expansions of explosives. Results between explosives were compared at large expansions; R-R0 of 19 mm. Early time results were of poor quality for two reasons. Magnification of the cylinder did not allow high resolution of the first few microseconds of expansion. Secondly, air shock produced by the copper wall for the first microseconds made analysis difficult.[8]

The addition of the Fabry Perot now allows for accurate and precise measurements of the early wall motion. When shocked the wall angle jumps 5 to 10 degrees from normal depending upon the explosive being tested. We have obtained very good results by first positioning the beam at 7 degrees and collecting a minimum return from a defuse spot on the cylinder.

The Fabry Perot wall velocity from a cylinder experiment was 3 % to 4 % below that of the streak cameras. The additional velocity from the streak cameras can be accounted for if one adds the motion due to the detonation wave moving up the tube to the radial expansion given by the expanding explosive products. By adding this phase velocity we obtain very good agreement between techniques.

REACTIVE FLOW MODELING

It has become clear from the flat plate and particle velocity measurements that old equations of state do not fit some results. This is especially true for explosives which have a finite time duration reaction zone. For some experimental techniques the reaction zone is too narrow to be observed. With the resolution of the Fabry-Perot, approximately 10 nano seconds, shown in Figure 5. Reaction zones are easily seen, as Hydrodynamic computer modeling is now required to handle the two phases of a detonation front. Firstly the spike which has a very high pressure and falls to a point which has been generally called the C-J [Chapman-Jouguet], and then the expanding detonation products.[4] In order to handle both we now use Reactive Flow modeling to handle both rates as shown in Figure 6.

COMPLETED EXPLOSIVE STUDIES

With the use of the Fabry-Perot we have refined Equation of States for several explosives. Some of the explosives completed are PETN, TNT, LX-17, LX-04, PBX-9404, and LX-14. We have repeated cylinder shots with Fabry-Perot and conducted both flat plate and particle velocity testing on these materials.

Use of the Fabry Perot has given chemists the ability to resolve chemical reactions during detonation which has been very difficult to do in the past. By conducting particle velocity tests one can determine carbon formation during the detonation product expansion. Tests were conducted to observe evidence of carbon formation in the detonation products of three explosives. PETN which does not form carbon and TNT and LX-17 which have carbon in their products were tested.[5] Explosives with multiple components have also been tested, such as Baratol[6] in which the percentage of barium nitrate reacting was determined. Solid propellants have also been studied for their multicomponet nature. They usually exhibit large reaction zones and have large failure diameters. Typically they contain an explosive component, rubbery binder, aluminum, energetic liquid, and an oxidizer. Several of these mixtures have been successfully characterized.

Presently we are conducting a series of tests on three composite explosives to determine how aluminum reacts. For the first test series we are using 5 micron spherical aluminum. The Table below lists the compositions tested. From these studies one can determine the optimum weight percentage of aluminum for the best performance.[7]

Table 4

Composition	Wt. % Aluminum
PETN/Aluminum	5,10,20,30,40
TNT/Aluminum	5,10,20,30,40
RDX/Aluminum	5,10,20,30,40

Lastly, one of the most important uses of the Fabry Perot has been the characterization of new explosives. These are normally formulated in very limited quantities of material. By using the electric gun and 25.4 mm diameter samples which weigh less than 20 grams each we can obtain free surface velocity and particle velocity information on qualities less the 100 gms of material. From these early tests one can determine if larger and more expensive tests should be conducted.

FUTURE STUDIES

The composite explosive series using the 5 micron spherical aluminum will soon be completed. The next phase of the project will be to use flake aluminum, which has a much larger reactive surface area than the spherical particles. Then we will add an oxidizer such as ammonium perchlorate or ammonium nitrate.

Some new high density energetic explosives are being scaled up presently. The first test series will be done using flat plate and particle velocity measurements as per Table 1. If they have good performance we will continue testing in larger experiments such as cylinder shots.

A new experimental technique we wish to pursue is to obtain both sideways wall velocity, as in the cylinder test, as well as head on, as in the flat plate test from the same experiment. This could be done using fiber optics and splitting the beam. From this one experiment we can measure large expansions much like the cylinder test, and also small expansions in the head on, flat plate tests.

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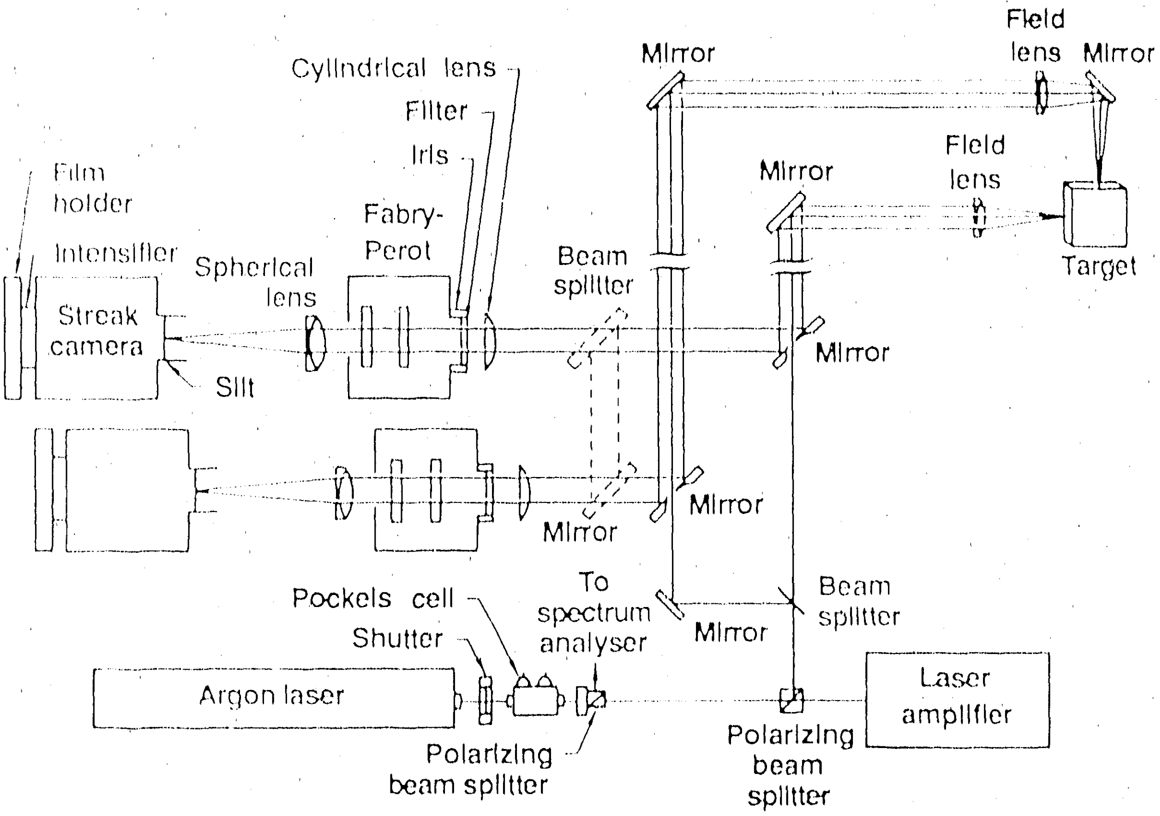

Figure 1. Layout of a Fabry-Perot experimental setup typically used at LLNL.

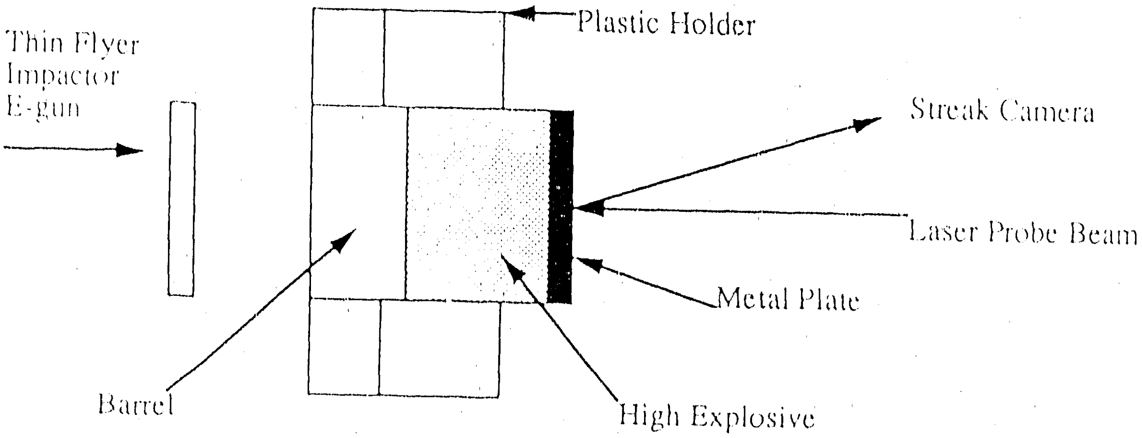

Figure 2. Flat plate experimental setup

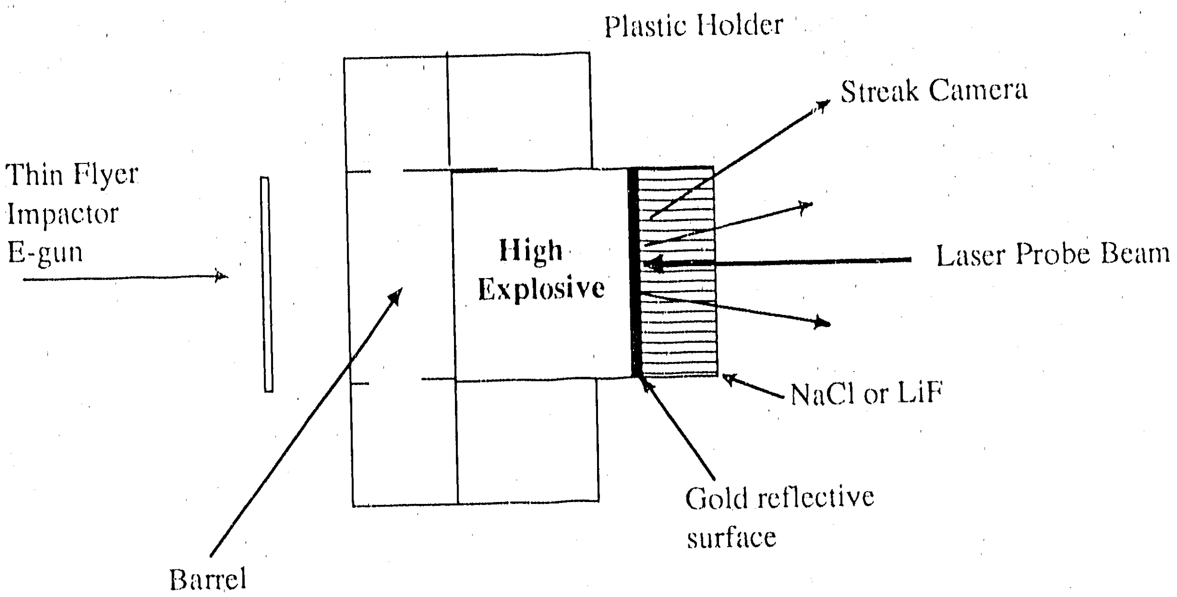

Figure 3. Particale velocity experimental setup.

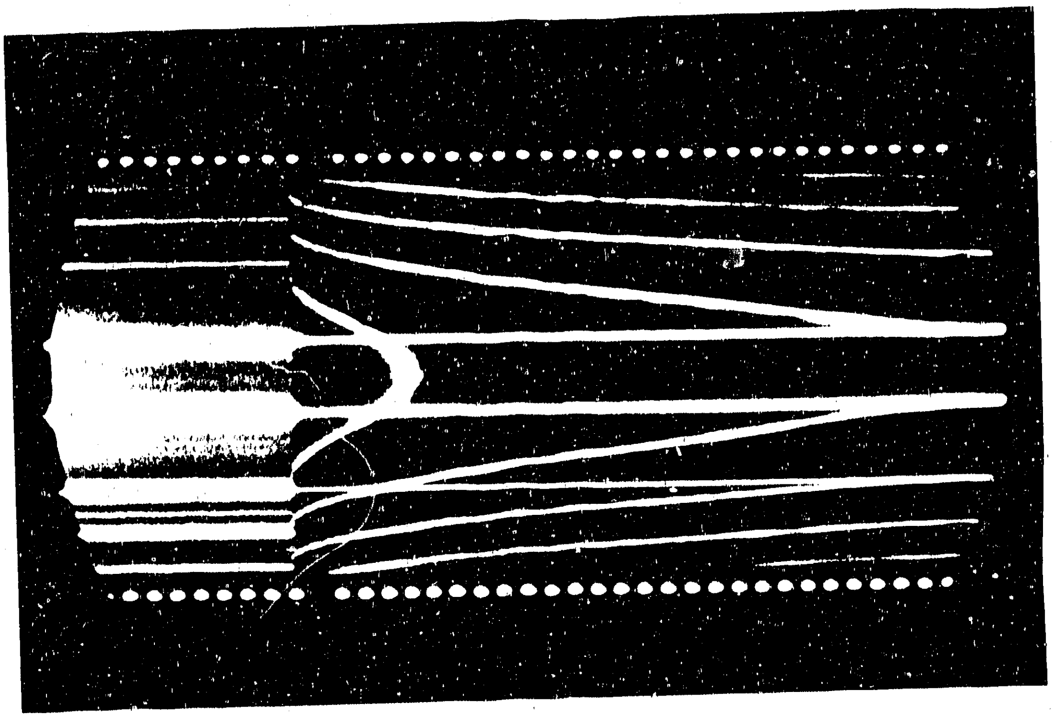

Figure 4. Particle velocity record.

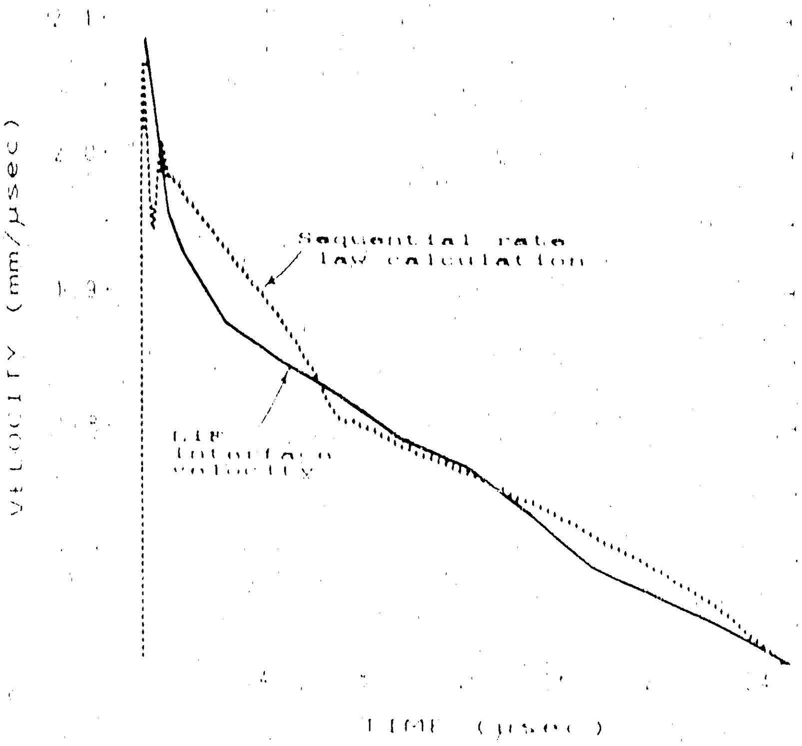

Figure 5. Two sequential rate laws were used, first going to 37 GPa and then going to 34 GPa.

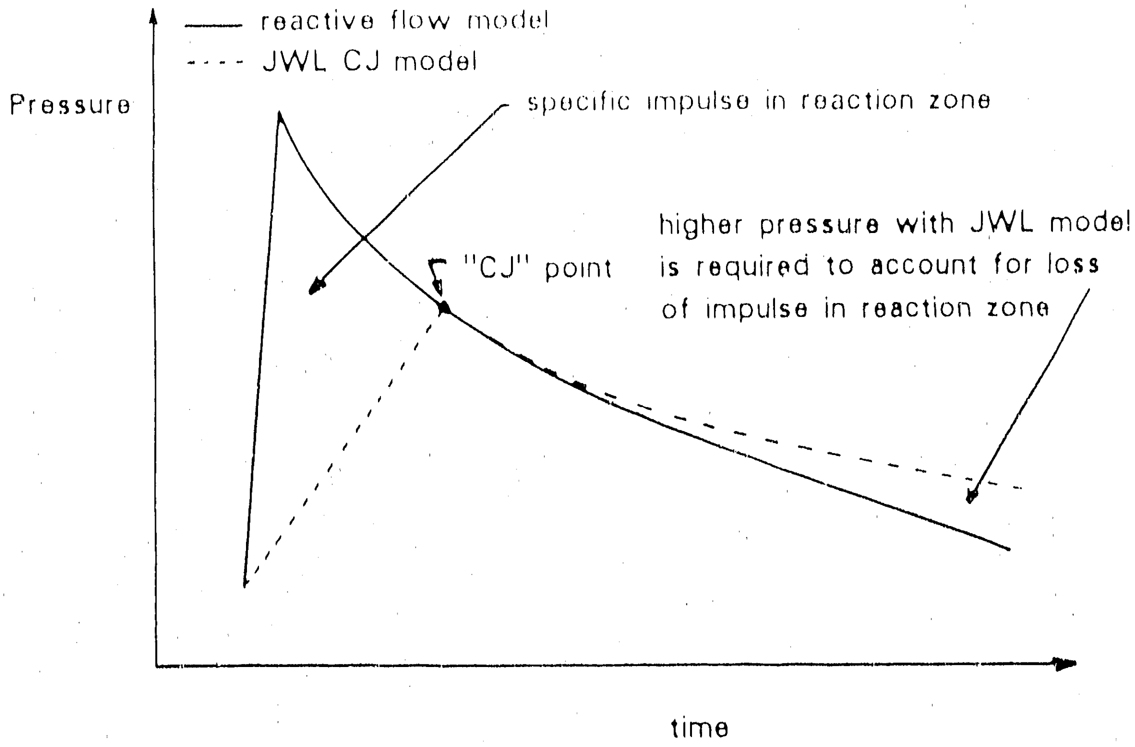

Figure 6. comparison of RF versus standard CJ prediction of pressure wave profile shows "specific impulse" in reaction zone.

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