nism of reaction prevails after the explosive passes out of the detonation head. For example, it is obvious that the rate law in ordinary explosive deflagration is quite different than that occurring in detonation; otherwise ideal detonation velocities would be rare. That is, reactions occurring at the rate obtained for explosive deflagration would appear to require very long reaction times and thus long reaction zones. (This point is discussed quantitatively later in this article.)

This article deals with the experimental results obtained from the "cannon" method for the determination of the reaction rate of 4–6 mesh and 8–10 mesh loose-packed TNT, and with a theoretical analysis of these results.

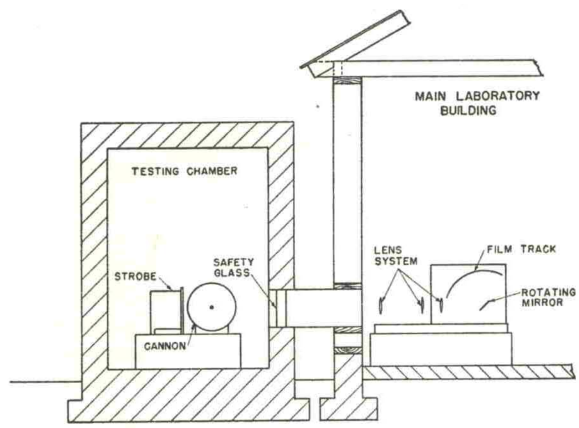

FIG. 4. Experimental arrangement.

EXPERIMENTAL EQUIPMENT AND PROCEDURE

The cannon used in this study for direct measurements of pressure was constructed in two sections, a barrel and a breech, each being made of a piece of steel 10 in. in diameter. The piece forming the barrel was 4 in. thick, and the one forming the breech was 6 in. thick. A one-half inch hole was drilled through the center of the 4-in. piece to serve as the bore, and a powder chamber about 5 cm diameter and 5 cm deep, having a volume of 103 cm^3, was machined in the center of one side of the 6-in. piece. These two pieces were held together by means of eight $1\frac{1}{2}$-in. diameter heat-treated steel bolts spaced around the circumference of the barrel about $1\frac{1}{2}$ in. from its edge that threaded into the breech parallel to the bore. The projectiles fired from the cannon generally were $\frac{1}{2}$-in. diameter aluminum shafting cut to a length of 6 in. and sharpened to a knife edge in order that the displacement of the leading edge might be accurately measured.

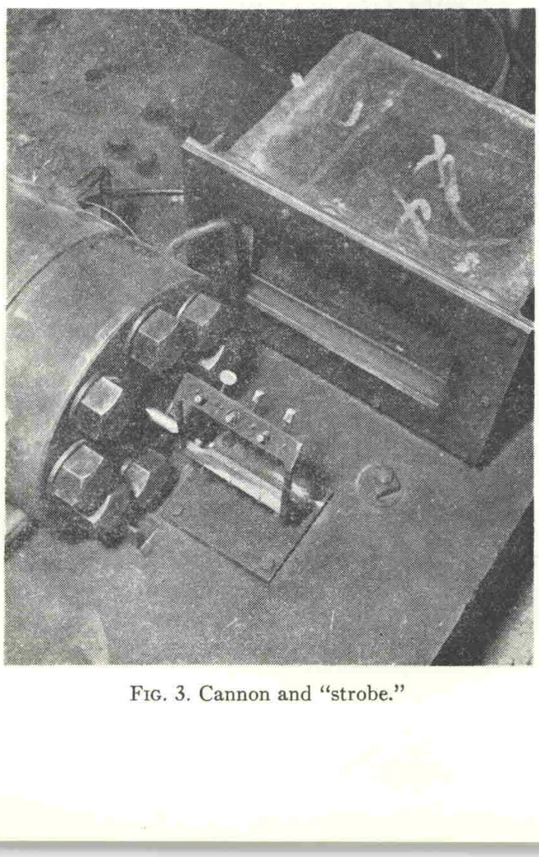

FIG. 3. Cannon and "strobe."

The charge was detonated inside the cannon with a special cap of negligible time delay initiated by the discharge of a 1-mfd capacitor charged to 5000 volts. The displacement of the knife edge of the slug was photographed with a rotating mirror streak camera. The camera was mounted inside a dark room in a building adjacent to the test chamber with a short tunnel connecting the chamber and the dark room. The leading edge of the slug was silhouetted by light from a xenon flash tube about 10 inches long, 8 mm inside diameter, and filled to a pressure of about 10 cm of mercury. This strobe was initiated in synchronism with the exploding bridgewire cap and flashed with a 230 mfd capacitor charged to 1000 volts. The tube was mounted with springs inside a steel box with a safety glass window and placed as close to the slug as possible. Adjustable legs were provided on the box in order that the height of the tube could be adjusted conveniently until its image fell along the slit of the camera. Proper distance scale was determined by taking each picture through a wire grid placed about $\frac{1}{8}$ in. behind the slug (see Figs. 3 and 4 for the experimental setup).

With this xenon light source, a 2 mil slit on the camera, Aerographic Super XX film, and a mirror speed of 200 rps corresponding to a writing speed of 0.638 mm/μsec, proper exposure was obtained with the objective lens set at $f/11$ which provided an effective over-all aperture of about $f/22$. The film trace (see Fig. 5) was then read with a Cambridge Universal Measuring Machine having a least count of 0.01 mm.

EXPERIMENTAL DATA

The data obtained from the "cannon" method consisted of a set of distance-time data (X_j, Y_j). The X_j values were proportional to the elapsed time and for convenience were recorded at equally spaced intervals, and the Y_j values taken were proportional to the displacement of the leading edge of the slug. From these data it was required to obtain the velocity and the

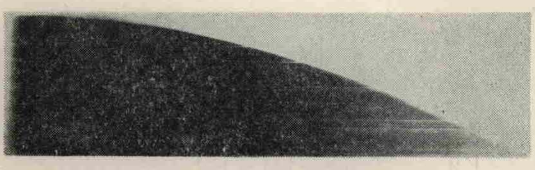

FIG. 5. Typical trace of accelerating slug.

acceleration of the center of gravity of the slug. It is well known that given a set of coordinates one can quite easily perform the mathematical operation of integration, but numerical differentiation is an exceedingly delicate task, and the accurate determination of second derivatives is much more difficult than for first derivatives.

The process of numerical differentiation was further complicated in this problem by the fact that besides the random errors made in setting the cross hairs properly on the film trace and taking the reading, there was a systematic error introduced because of longitudinal vibrations set up in the slug by the initial shock. These vibrations, in other words, were caused by a longitudinal wave which traversed the slug and was reflected at its ends. The film trace thus consisted of the displacement of the center of gravity of the slug superimposed upon which was a rapidly damped oscillation caused by the multiply-reflected longitudinal wave. These oscillations appeared to have about a 60 μsec period in the 6-inch aluminum slug which was in good agreement with the speed of sound in aluminum (5100 m/sec). It was hoped that a material could be found that would be more suitable for slugs than aluminum. Such a material, in addition to being low enough in density that reasonably high accelerations would be experienced, should be rigid enough that the initial amplitude of the vibrations be small and possess a high enough internal viscosity for the vibrations to damp out rapidly. This material should also be sufficiently strong not to shatter under the initial impulse. While various materials were tried, nothing more satisfactory than aluminum was found and since aluminum gave rather good results, no extensive study of projectile materials was undertaken.

Because of the random errors made in reading the film and the oscillations that were set up in the slug by the initial shock of the explosion, it was necessary to apply some kind of smoothing process before any method could profitably be applied to obtain the derivatives. The smoothing was done with an IBM computing unit using a method of least square polynomials over moving arcs outlined by Trimble.[7] Briefly the operation was as follows: A polynomial of chosen degree was fitted to $2n+1$ points by least square methods, and the value of the polynomial at the $n+1$st point was taken as the smoothed ordinate at that point. The arc was then shifted one coordinate each operation, and the process repeated until smoothed ordinates were obtained for all the points except the n points on each extreme end of the data. The calculations were expedited by means of a recursion relation which allows one to calculate conveniently the smoothed ordinate using the preceding polynomial. The data were usually smoothed twice or until the second derivatives were fairly regular.

Any smoothing process must necessarily change the data to some small extent, but it was felt that the above method did justice to the data. The initial oscillations on the film trace appeared to have amplitudes of the order of 0.1 mm, and along this portion of the trace some of the smoothed y's differed from the original Y's as much as this amount. However, these oscillations in general decreased in amplitude fairly rapidly, and then the smoothing process in the main merely added more decimal places to the readings. The derivatives were calculated according to a method of Rutledge.[8] Briefly the process consists of passing a 4th-degree interpolating polynomial, $y(\lambda)$, through five consecutive smoothed points and evaluating the derivatives at the midpoint of the interval by means of the polynomial. The second derivatives were then smoothed by graphical means. An evaluation of the validity of the derivatives thus obtained is given in the Appendix of this article. The results of the evaluation point to the conclusion that in spite of the oscillations of the slug the derivatives obtained are very good, except for the first 10–15 microseconds at the start, and this region is of no interest.

EXPERIMENTAL RESULTS

Pressure-time measurements were first attempted for pure 4–6 mesh TNT at an average loading density of 0.39 liter/kg, but it was found that the pure coarse TNT could not be detonated in the cannon with a cap. This was not surprising since for unconfined charges of this mesh TNT a booster is required for initiation, and propagation failure occurs in charges less than 5 cm in diameter. However, because of the heavy confinement of the cannon, it was found possible to ignite the pure

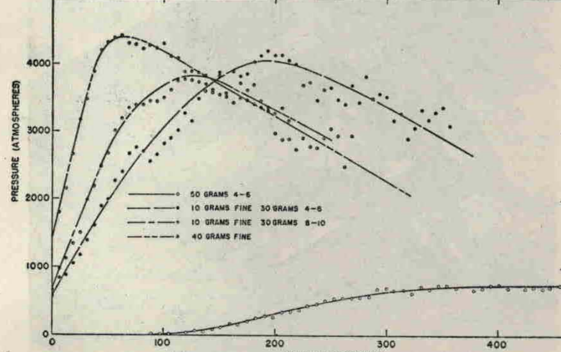

FIG. 6. Typical pressure-time curves.

[7] G. R. Trimble, Jr., Proceedings Computations Seminar, August 1951, p. 93, IBM, New York.

[8] G. Rutledge, Phys. Rev. 40, 262 (1932).