

A PHOTOGRAPHIC TECHNIQUE FOR MAPPING
FAILURE WAVES AND OTHER INSTABILITY
PHENOMENA IN LIQUID EXPLOSIVES DETONATION

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Summary:

The open camera aquarium technique has been found to be a powerful technique for recording dynamic instabilities in the detonation of liquids.

The present paper gives a few examples of recordings and a tentative theory of failure waves. It was submitted as a discussion paper at the 5th NDL Symposium (International) on Detonation at Pasadena, August 18-21, 1970.

A Photographic Technique for Mapping Failure Waves and other
Instability Phenomena in Liquid Explosives Detonation

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We have found the open camera aquarium technique (Winning 1954, 1958, Johansson and Sternhoff 1959) to be a very powerful and simple instrument for making measurements of the failure waves and other instability phenomena in detonating liquid explosives. A charge of liquid explosive in a transparent casing such as a glass tube is immersed in water in an aquarium. In this way, and by placing the charge and camera in darkness, the only light that reaches the film of the open shutter camera is that emitted from the very thin reaction zone when it sweeps through the charge. The record is a picture of the charge, having the same outline as before detonation because very little gross motion takes place within the reaction zone. We have found that the variations of temperature and reaction time associated with failure waves in pure nitromethane are clearly visible as a pattern in such records.

Figure 1 shows the still picture (a), and reaction light recording (b) of a tubular charge nitromethane in a 19.5/22 mm (internal/external diameter) glass tube, emerging into a wider tube, also filled with nitromethane. Initiation was done from below by the 84 mm long and 29 mm diameter pressed TNT booster through an 0.25 mm PVC barrier. The record shows a fine criss-cross network of failure waves at the surface on the 19.5/22 mm glass tube. At the top is seen the integral picture of the light emitted from the complicated failure and reinitiation processes after the detonation emerges into the wider tube. Outside the main contour of the glass envelope of the charge, there is a faint halo-like light. We believe this to come from the reaction products during their relatively slow expansion behind the reaction zone.

Figure 2 shows a series of four separate records of four different shots of pure nitromethane in straight tubes of ca 150 mm length, all initiated by the same booster system as in fig. 1. In the record 2a the envelope was a 19.5/22 mm glass tube, in 2b and 2c (identical charges) 15.5/17.9 mm glass and in 2d 16 mm internal diameter 0.07 mm thick mylar.

Figure 2a shows, perhaps more distinctly than fig. 1a, the criss-cross pattern of intersecting failure waves. In figure 2b and c, with a diameter closer to the critical diameter, the wave pattern is coarser.

Figure 2d shows the pattern of detonation failure obtained when the tube wall was made of thin mylar instead of glass.

On the basis of the patterns of figure 2a, b and c we suggest the following theory for the failure wave.

Assume that the detonation is most sensitive to slight disturbances at the wall. This is where the reacting explosive is most directly accessible to the effects of the lateral expansion. The paper by Persson and Sjölin in these proceedings shows very clearly how extremely sensitive the detonation reaction is to changes in front pressure. Thus, it appears likely that, given a slight local disturbance to the detonation at a point on the wall, reaction will effectively stop at this point, to restart again only after a given initiation induction period has elapsed. The reaction failure will spread as an expansion wave along the detonation shock front so that a volume of the explosive within a conical surface will be left unreacted. The conical surface has its apex at the initial failure point and its axis in the direction of detonation. If the detonation front were plane and perpendicular to the tube axis, the cone would be straight and its half angle α would be given by:

$$\operatorname{tg} \alpha = (1/D) \sqrt{C_f^2 - (D - u_{pf})^2} \dots\dots\dots (1)$$

where D is the detonation velocity, u_{pf} the detonation front particle velocity and C_f the sound velocity in the shock compressed but unreacted explosive at the front of the steady detonation reaction zone.

After the initiation induction period has elapsed, reinitiation takes place at the cone apex. A detonation wave will spread spherically out from this point through the shock compressed unreacted explosive within the cone and will eventually catch up with the shock front. Catch-up will occur first at the tube surface and later further in. The catch-up surface will be forward concave. Figure 3 shows a schematic illustration of the process in two longitudinal and two perpendicular views of the tube. Failure and re-initiation takes place at the point A, failure spreading along the cone generator AC. B is the point of first and C (also D) that of last catch-up.

The intersection between the failure cone and the tube wall is the lines DAD, and that between the catch-up surface and the wall the line DBD. Thus, because the detonation in the pre-compressed material affected by the failure is less luminous than the ordinary detonation, the surface ADBDA will appear dark. Also, because of the higher than normal light intensity from the detonation immediately after catch-up, the surface BDCDB will appear lighter than the surrounding.

These features are modified by the curvature of the real detonation front and the interaction between a multitude of failure waves. Using the values $D = 6.39$ km/sec, $C_f = 5.05$ km/sec, and $u_{pf} = 2.52$ km/sec, in equation (1) we arrive at the value $\alpha = 27^\circ$, which is in the range suggested by figures 2a, b and c.

In a perpendicular cross section of the tube, such as that seen by a camera looking down the tube, the zone of unreacted material would appear as a half-circular dark band or a half-circular dark surface depending upon whether or not catch-up has occurred. These are obviously the failure waves observed by Watson (these proceedings) in framing camera pictures and by others in streak camera with the slit across a diameter of the tube. In the latter records, the similarity with the cross sectional, dashed line surface ACBA is striking.

With the mechanism suggested, it would appear likely that the disturbance due to the initial failure at A spreads further along the cone surface than to the final catch-up DCD. We suggest that such "ripples", propagating sideways within the reaction zone and following for long distances the conical surface, are the origin of the detonation wave fine structure first observed by Cotter (1956).

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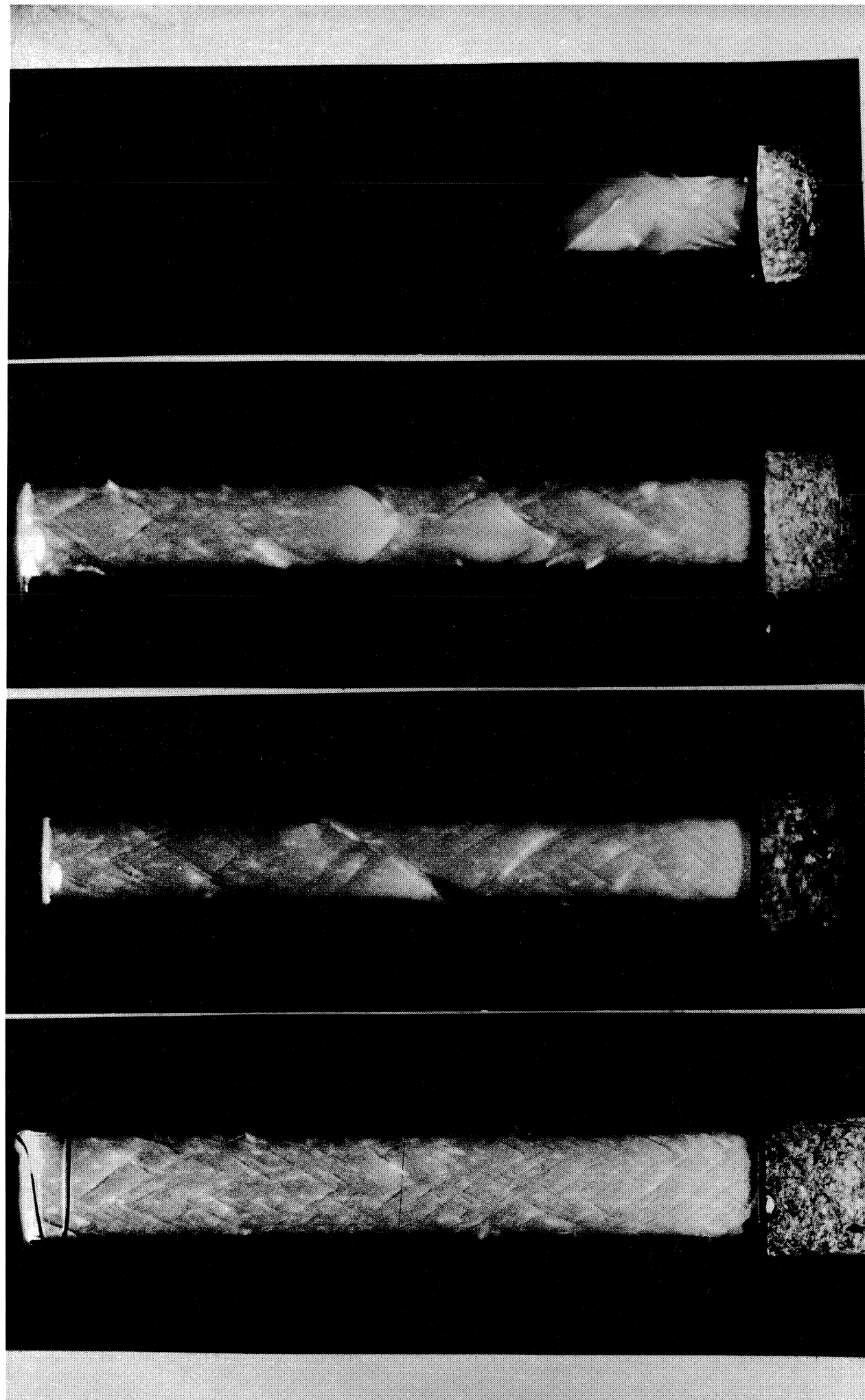


Fig 2. Detonation light records using the open camera of detonation in pure nitromethane in 150 mm long tubes of diameter 19.5/22 mm glass (a), 15.5/17.9 mm glass (b) and (c), 16 mm i.d. 0.07 mm thick mylar (d).

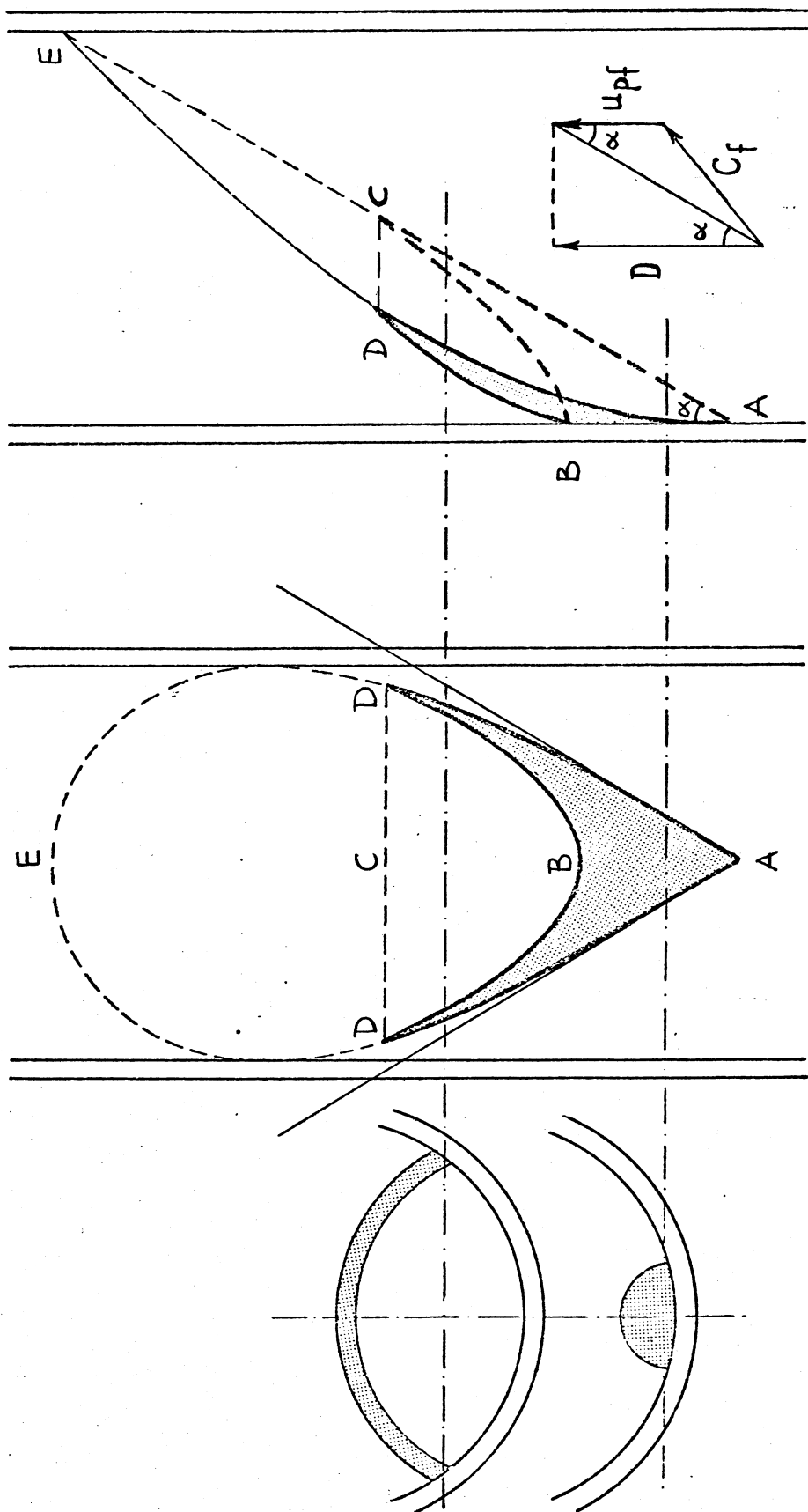


Fig 3. Schematic illustration of the geometry of failure and reinitiation waves in liquid explosive detonating in a tube.