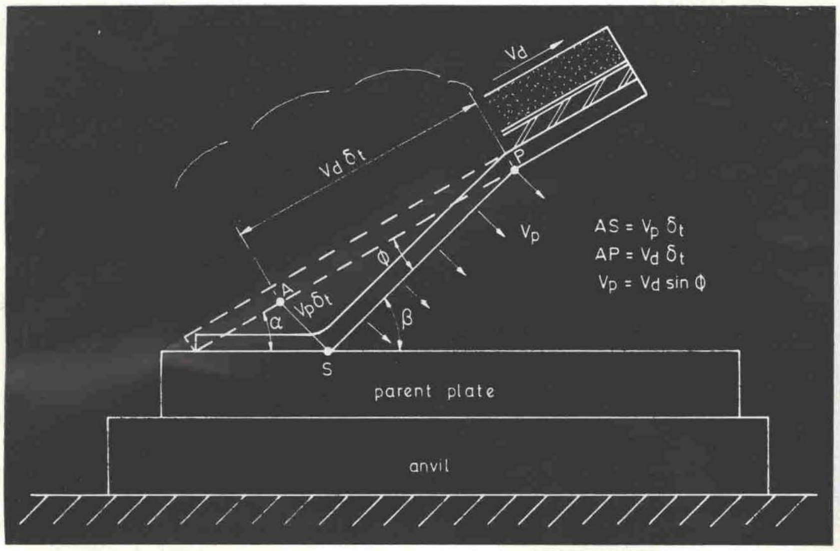
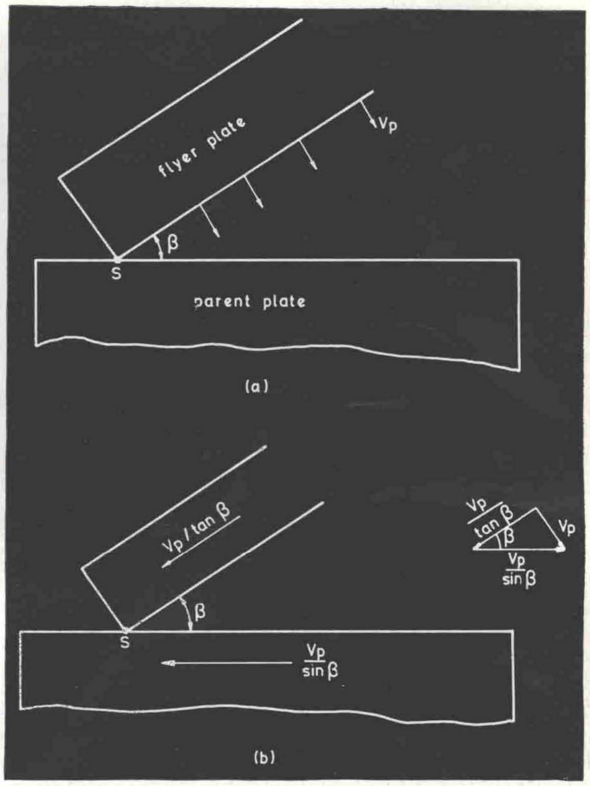




△

3 Mode of collapse of flyer plate

4 Change of co-ordinates for impacting plates. (a) Initial state; (b) change of co-ordinates.

Fig. 3 to rest and to do this it is necessary to apply a backward velocity of $V_P/\sin\beta$ to the parent plate, as shown in Fig. 4. If this backward velocity is applied to the system, then the velocity of the flyer plate is $V_P/\tan\beta$ towards S. Thus, the system becomes equivalent to a liquid jet of velocity $V_P/\tan\beta$ impinging a stream travelling at a velocity $V_P/\sin\beta$ at an angle of incidence of β. The liquid jet impinging the stream at S is deflected into a horizontal direction, still travelling at the same velocity, but this implies that the conservation of momentum in the horizontal plane has not been satisfied. Consequently, it must be concluded that the jet divides into salient and re-entrant jets, as shown in Fig. 5.

Applying the conservation of momentum gives

$$m\frac{V_P}{\tan\beta}\cos\beta = m_s\frac{V_P}{\tan\beta} - m_r\frac{V_P}{\tan\beta}$$

or

$$m\cos\beta = m_s - m_r \qquad \ldots [2]$$

Conservation of mass dictates that

$$m = m_s + m_r \qquad \ldots [3]$$

From equations [2] and [3]

$$m_r = \frac{m}{2}(1 - \cos\beta) \qquad \ldots [4]$$

$$m_s = \frac{m}{2}(1 + \cos\beta) \qquad \ldots [5]$$

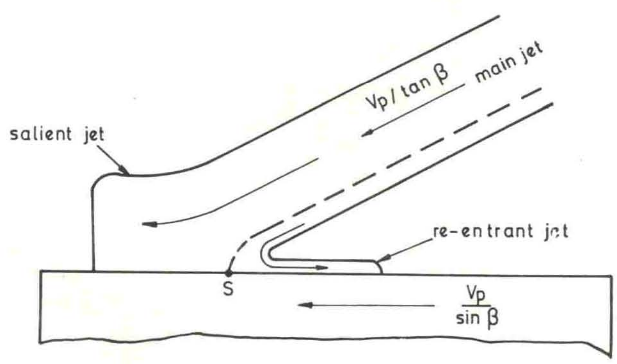
and the absolute velocity of the re-entrant jet will be

$$\frac{V_P}{\tan\beta} + \frac{V_P}{\sin\beta} = \frac{V_P}{\sin\beta}(1 + \cos\beta) \qquad \ldots [6]$$

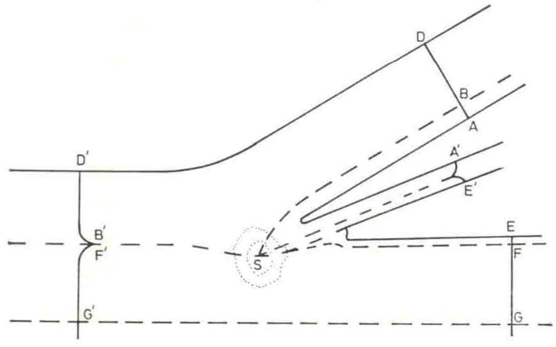
The analysis is of course strictly applicable only when the velocities of the flyer and parent plates relative to S are less than the velocity of sound in the materials of the two plates, as it ignores compressibility effects.

Walsh, Shreffler, and Willig[27] considered the case where the velocity of the main jet, $V_P/\tan\beta$, is supersonic by using compressible flow theory. If the main jet velocity substantially exceeds the sonic velocity, then attached shock waves in the flyer and parent plates will travel with the point of impact S and no re-entrant jet is produced. For a main jet velocity that is not substantially greater than the sonic velocity, there is a critical angle above which the shock wave becomes detached from point S and moves upstream so that the pressure is felt in front of the point of impact, and in these circumstances a jet can be formed.

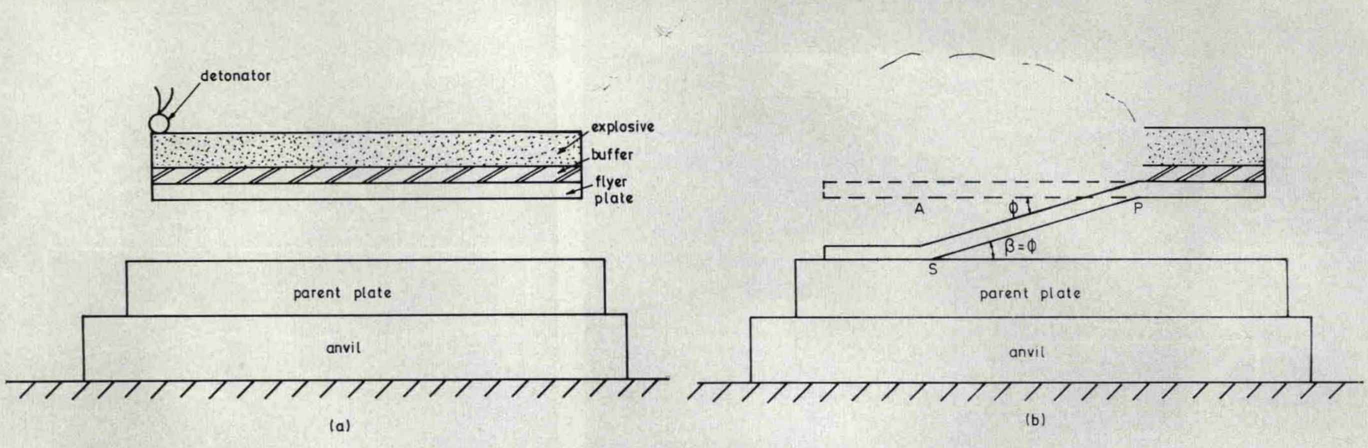
The existence of a jet in explosive welding has been hotly argued, but its existence has been confirmed by Holtzman and Cowan,[21] who employed flash X-ray to



5 Formation of salient and re-entrant jet.



6 Flow configuration in the region of collision.



7 Arrangement for explosively welding parallel plates. (a) Before detonation; (b) a short time after the initiation of detonation.

obtain pictures of a jet. Bergmann *et al.*,[22] using a framing camera, have also substantiated the existence of a jet. The existence of a jet can also be deduced from experiments in which one or both of the collision surfaces are plated with a tracer layer of another metal, as reported by Holtzman and Cowan,[21] Bahrani *et al.*,[25] and Lucas *et al.*[28] In some cases jets which are more in the form of a spray than a concentrated jet have been observed.

Essentially, in explosive welding a jet is necessary which is formed from the underneath surface of the flyer plate and which picks up by surface traction the top surface of the parent plate. It is also generally believed that a plastic zone in front of the contact point is required to aid in the removal of the surface contaminant film. Perhaps the plastic straining helps to break up the oxide film and this may be aided by the formation of a hump in front of the jet. Figure 6 shows the flow configuration in the region of collision. It will be seen, considering sections ABD and EFG, that layers AB and EF are removed and points B and F will be brought together as shown by D′B′F′G′.

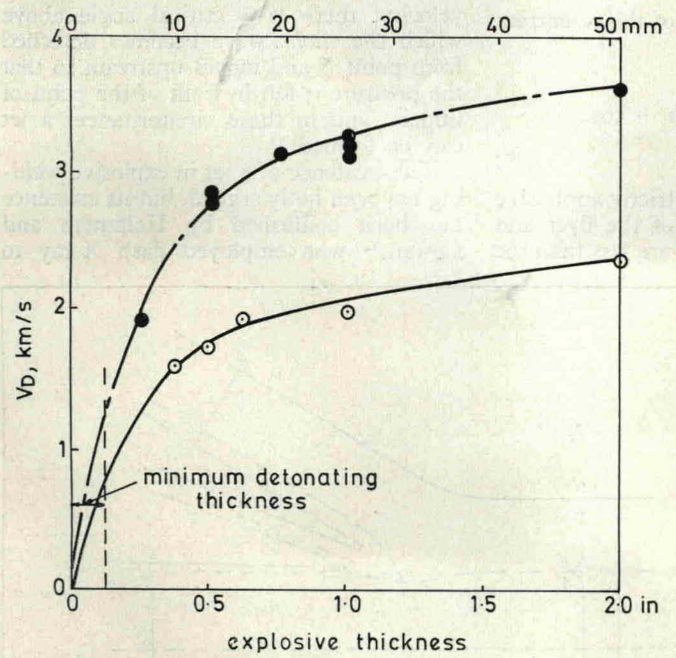
The above conditions can be met with a parallel plate set-up with an initial clearance between the flyer and parent plate, if an explosive is used that has a detonation velocity less or only slightly greater than the sonic velocity. This is shown in Fig. 7, which illustrates the parallel-plate set-up in which the detonation velocity is assumed to be equal to the sonic velocity. It will be seen that the velocity of the contact point is equal to the detonation velocity, and

$$\beta = \sin^{-1} V_P/V_D \qquad \ldots [7]$$

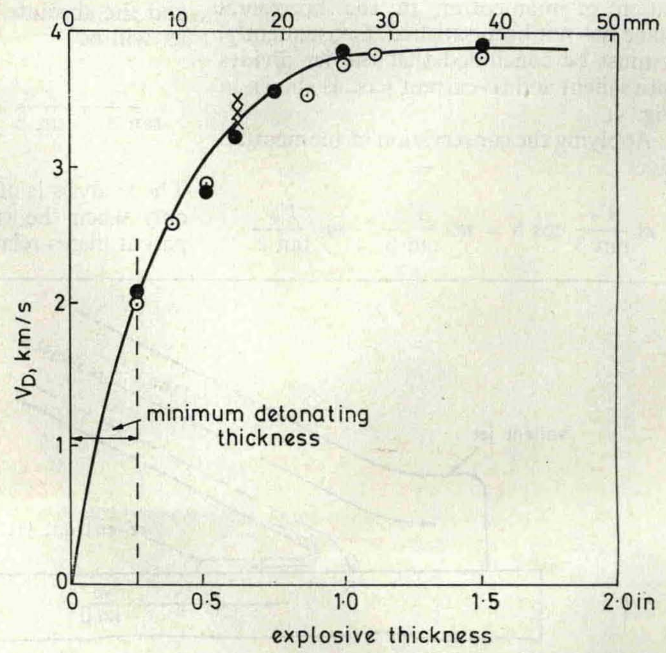
As a result the velocity of the flyer plate relative to S, $V_P/\tan\beta$, is $< V_D$ so jetting can occur and welding is possible.

From the foregoing it will be realised that the important parameters in the process are the detonation velocity of the explosive and the velocity imparted to the flyer plate. Values of detonation velocity are given by the explosives manufacturers; also values are quoted by Wright and Bayce[20] and these are given in Table I.

However, it is well known that the detonation velocity is dependent on the diameter of charge or thickness of layer, and this is of considerable significance in explosive welding where, with some explosives, the thickness of layer used is within the region where it will have a considerable effect on the detonation velocity. For instance, Fordham[29] gives the data reproduced in Table II.



8 Effect of thickness of layer of explosive on detonation velocity for *Trimonite No. 1*: ○ granules, parallel plate, $\rho = 0{\cdot}712$ g/cm^3; ● powder, pin insertion, $\rho = 1{\cdot}1$ g/cm^3.



9 Effect of thickness of layer of *Trimonite No. 3* on the detonation velocity. $\rho = 0{\cdot}98$ g/cm^3.
○ Dautriche × parallel plate ● pin insertion