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NO GR. DOT

G. B. Kistiakowsky

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H. A. Bethe

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Memorandum on Shaping the Liner

The problem of shaping the liner instead of introducing lenses into the explosive has been considered during the past week. It has become clear that it is not possible to achieve a really symmetric implosion in this way. The reason for this is that there are four different quantities which should be made symmetric whereas there are only two variables which can be chosen arbitrarily. For a perfect implosion it would be necessary to fulfill the following four conditions:

(1) The velocity must be directed radially at all points.

(2) The shape of the imploding shell after it has received its complete acceleration must be spherical.

(3) The velocity must be the same for all points of the shell.

(4) The thickness of the shell must be uniform.

This last condition is necessary in order that the accelerations due to focusing be uniform over the sphere.

To achieve symmetry we can vary the following two quantities: (a) The shape of the liner and, (b) the thickness of the liner as a function of the azimuth.

It is obvious that with two quantities to vary it will not be possible to fulfill four independent conditions except by accident. It can be shown however that this accident will not occur.

Probably the most important requirement is that there be no corners in the imploding sphere which might give rise to shape charge effects. The corners in the usual implosion are believed to be due to faulty timing, i.e. to the fact that the detonation wave arrives earlier at the points immediately under the detonation points than at the points midway between. A simple theory, first given by Greisen, shows that an initially spherical shell will be deformed towards a polyhedral shape to an extent given by the quantity

$$K = \frac{v}{D} \frac{b}{b - a} \qquad (1)$$

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where v is the final velocity of the liner, D the detonation velocity, b the outer radius of the explosive, and a the outer radius of the liner. If K is equal to one, the shape of the liner will be deformed exactly to a polyhedron with flat faces; if K is smaller than one, as it usually is in practical cases, the faces of the polyhedron will still bulge out and K gives the fraction of the deformation from a sphere to a polyhedron which has taken place. Whether or not K is equal to or smaller than one, there will be sharp corners at the points midway between detonation points at which jet formation will take place.

We have calculated the direction of the velocity given to the liner initially. In sufficient approximation this direction is midway between the normal to the original surface of the liner and that to the surface after acceleration. This shows that the conditions one and two above are different. We might for instance correct by shaping the liner so that its shape after acceleration will be a sphere. This is illustrated in Fig. 1. If we do this the velocities will not be directed radially but will be directed more toward the center of the section so that the given section of the liner will converge to a point this side of the actual center of the sphere. It is therefore obvious that we have over-corrected the shape of the liner. We shall certainly have eliminated any jet formation at the interaction points but we shall have instead at a later time some shape charge effect under the detonation points. It is possible that this effect will not be as serious as the effect observed in past experiments.

Alternatively we may correct for the velocity which requires an initial deviation from the spherical shape half as large as the one previously considered. In this case the velocity will be directed towards the center of the sphere but the shape of the liner after acceleration will deviate from a sphere in the opposite way from the original shape of the liner (Fig. 2). In this case there will not be any shape charge effect at the corners initially, but as the material converges the inner surface will be accelerated and this acceleration will be perpendicular to the present inner surface and therefore will lead to an accumulation of matter at the intersection of detonations. This accumulation will be only a secondary effect and will therefore be less important than it is with an initially spherical liner. However, it is clear that in this case we have not corrected sufficiently.

It is quite doubtful whether it is at all possible to make a perfect correction. It seems likely to us that at some intermediate shape, we shall get accumulation of matter and therefore jet formation <u>both</u> at the intersections and under the detonation points. It is possible that in this case the jet formation will not be serious at either of these two points but it seems unlikely that it can be avoided entirely. In any case it may be worth trying experiments with a shaped liner intermediate between the two cases discussed above, i.e. with a deviation from spherical shape of perhaps two-thirds the deviation necessary to make the shape after acceleration spherical.

As regards the thickness of the liner it is much more difficult to make reasonable predictions. On the one hand the acceleration given by the explosive will decrease as we go away from the detonation point; on the other hand there will be an extra high acceleration at the intersection of two detonation waves. It is especially difficult to make predictions on the acceleration to be expected near the intersection. However, from the experiments of Greisen it appears that the uniformity of velocity may be less important than the correct timing.

If we wish to correct for the thickness of the power of a single detonation wave we should make the decrease vary approximately as

$$(\cos \alpha)^{-1/2} \qquad (2)$$

where α is the angle between detonation wave and the direction of the velocity after acceleration. Eq. (2) is based on the approximate dependence of liner acceleration on mass ratio. Variation of the thickness according to Eq. (2) will make the initial velocity of the liner approximately uniform over the sphere. However, this uniformity will be destroyed by the subsequent focusing effect which will give greater acceleration of the inner surface at the points where the liner thickness is greater. This would mean that the liner below the detonation point will ultimately attain higher velocity. This would require a greater variation of thickness. Probably a variation as $(\cos \alpha)^{-1}$ will be reasonably satisfactory.

No attempt has been made to estimate the thickness required at the intersection of two detonation waves. Our present knowledge of the pressure at the intersection is very meager and it is quite doubtful whether much improvement in this situation can be expected. Certainly a greater impulse will be transferred to the liner at the intersection points and the liner should therefore be increased in thickness at these points. It is not known how far the effect of the intersection points will extend. In view of these uncertainties, I feel reluctant in giving any specifications on the thickness of the liner. I think these uncertainties are great enough to make a spherical shape of the outside of the liner as good as any other. This will obviously not correct for the effect described by Eq. (2) but may reasonably correct for the extra pressure at the intersections.

The shape of the liner described in the beginning of this memorandum to correct for timing refers of course to a thin liner. For a thick liner this shape should probably be given to the layer midway between inner and outer surface. This means that if the outer surface is to be a sphere, the inner surface should deviate from a sphere by twice the amount recommended previously. This opens the possibility of correcting the inner surface by the full amount K of Eq. (1) and thereby making the velocity radial over the whole sphere as well as making the inner surface spherical after acceleration. Then at least in the beginning the inner surface will remain spherical even after the shell has thickened and the inner surface has been accelerated thereby. Of course this design will still leave differences in velocity uncorrected, but it will also give a shell of non-uniform thickness. However, I think that this design is about as satisfactory as can be made with our ignorance of the interaction of detonation waves.

Summarizing I want to reiterate that in my opinion no really satisfactory design on this basis can be made. However, I believe that the shape of the liner may cure the most flagrant asymmetries of the implosion, and that experiments in this direction would be of some value. The only way to fulfill the four conditions mentioned in the beginning is to use a spherical liner of uniform thickness and to make the detonation itself spherical, the only visible means for which at the present time is the use of lenses.

H. A. Bethe

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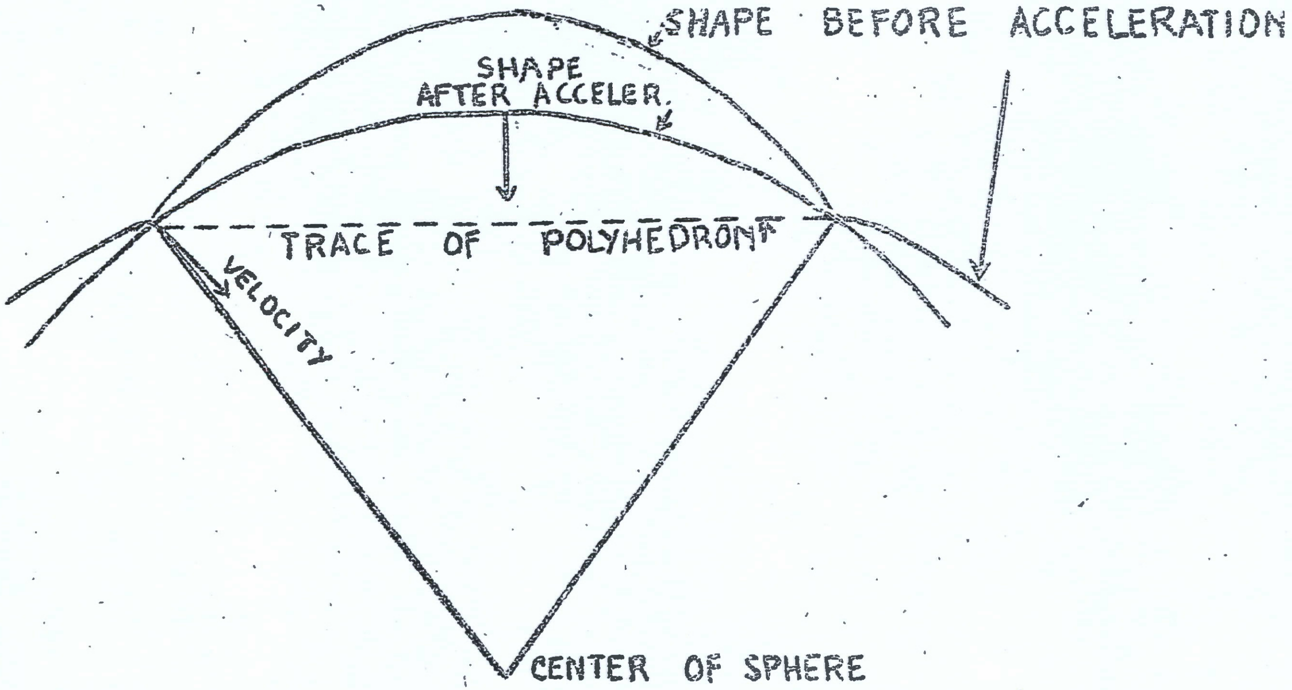

FIG. 1

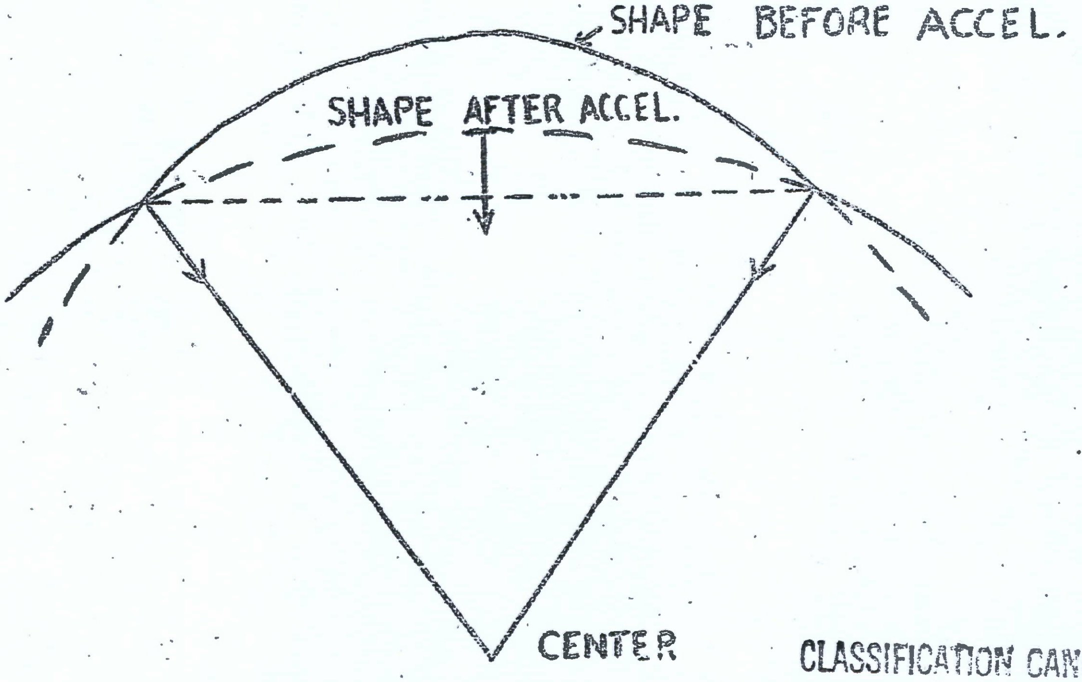

FIG. 2

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From H. Bethe

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EXPLOSIVE LENSES

We wish to propose a new simple design of explosive lens which also has some additional advantage in making the geometric optics more applicable. There are two purposes for which we would like to have lenses, namely, to focus the detonation wave on a plane and to focus it on a point.

I. The focusing of the wave on a plane was accomplished on our older design by a lens consisting of high and low velocity explosive separated by a boundary of the shape of a hyperbola. The detonation point was to be at the far focus of the hyperbola. We now propose to replace the hyperbola by two sides of a triangle and to have the detonation point at the apex of the triangle as shown in Figure I. This is the limiting case of the previous design. The sides of the triangle make an angle α with the base where

$$\sin\alpha = \frac{1}{n} = c_2/c_1$$

where n is the refractive index of the lines and c_2 and c_1 are the detonation velocities in the slow and the fast explosive respectively.

This arrangement seems to us to have three main advantages:

1.) It is simpler than the previous arrangement.

2.) The distance of the detonation point from the base has the smallest possible value for a given length of base.

3.) The detonation wave in the high velocity explosive travels along the boundary between the two explosives which is the case in which geometric optics has been found to hold by previous experiments. In our old design the detonation wave from the high velocity explosive hit the low velocity one head-on which caused deviations from geometric optics which were found experimentally by you and which were expected theoretically. These deviations would be likely to cause considerable trouble in constructing perfect lenses.

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For the lens proposed we should like to have investigated the following points.

1.) The shape of the detonation wave at the base of the triangle which should be a straight line.

2.) The shape of the wave somewhat beyond the base—it would be a straight line with circles at the end.

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For the low velocity explosive one may consider an explosive of low density or a heavy one. The latter type such as baronal is likely to be preferred for our purposes, but we have some doubt whether it can be made in a reproducible way.

II. We also wish to have a lens to focus the detonation on a circle. This can be accomplished by having the boundary between high and low velocity explosive in the shape of a logarithmic spiral. Denoting the center of the circle on which the explosive is to be focused by A the spiral should make an angle of 90° plus α with the radius from A at every point where α is given by eq. (I). This gives for the equation of the logarithmic spiral

$$r = ae^{\pm \theta \tan \alpha} = ae^{\pm \frac{\theta}{\sqrt{n^2-1}}}$$

It is desired to have the angle θ go through about 30°. With this arrangement it is expected that the detonation front in the low velocity explosive has the shape of a circle around A at every point. It would be desirable to investigate the shape of the front at one point near the base of the lens, at a point about half way down the lens, and finally, at a point somewhat below the base.

In this arrangement the detonation wave is expected to travel along the boundary between the two explosives in the high explosive which is supposed to guide the detonation wave in the low velocity explosive. After arriving at the base of the lens, a converging spherical detonation wave is supposed to be set up. Except for the curvature of the boundary, the arrangement is essentially the same as in the first case.

HB;eb

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