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Conger

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[54] **EXPLOSIVE LUNEBERG LENS WARHEAD**

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[73] Assignee: **The United States of America as represented by the Secretary of the Navy,** Washington, D.C.

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[52] **U.S. Cl.** **102/67,** 102/56, 102/DIG. 2

[51] **Int. Cl.** **F42b 13/48,** F42b 1/00

[58] **Field of Search** ..... 102/7.2 X, 8, 9, 10, 16, 102/56, 57, 58, 59, 63, 64, 68, 69, 89, 23 CW

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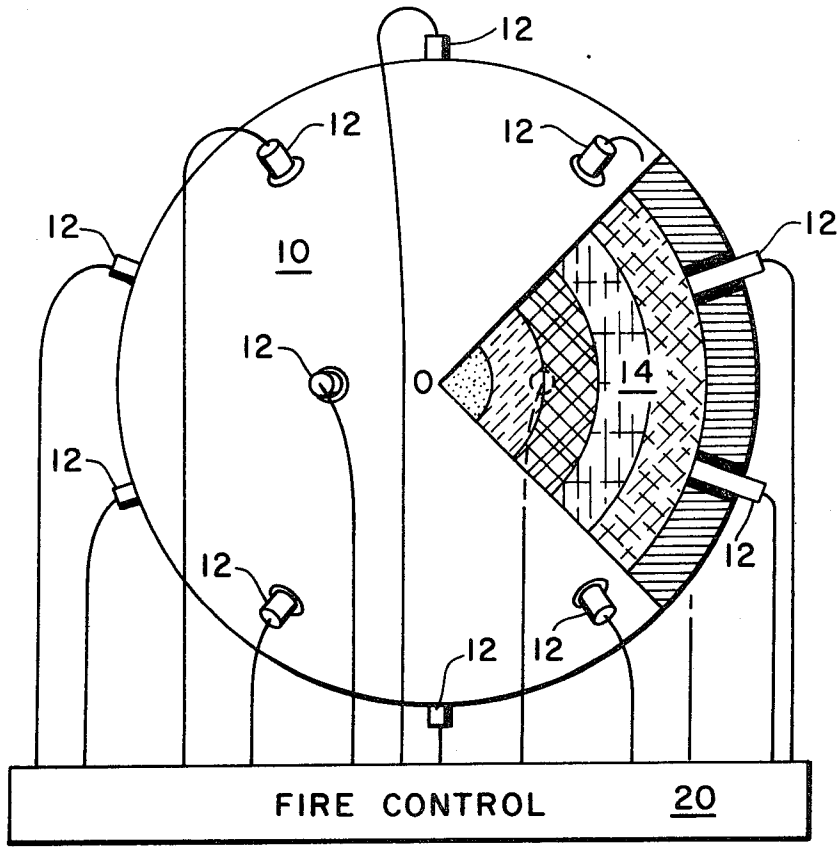
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[57] **ABSTRACT**

An aimable warhead in the form of an explosive Luneberg lens with individually controlled detonators evenly spaced about its spherical surface for aiming and firing same in any given direction by detonating a specific detonator on a side of the warhead opposite to the direction of aim, and containing a plurality of concentric spherical shells of explosive which upon detonation develop an explosive plane wave that propagates in the direction of aim.

2 Claims, 5 Drawing Figures



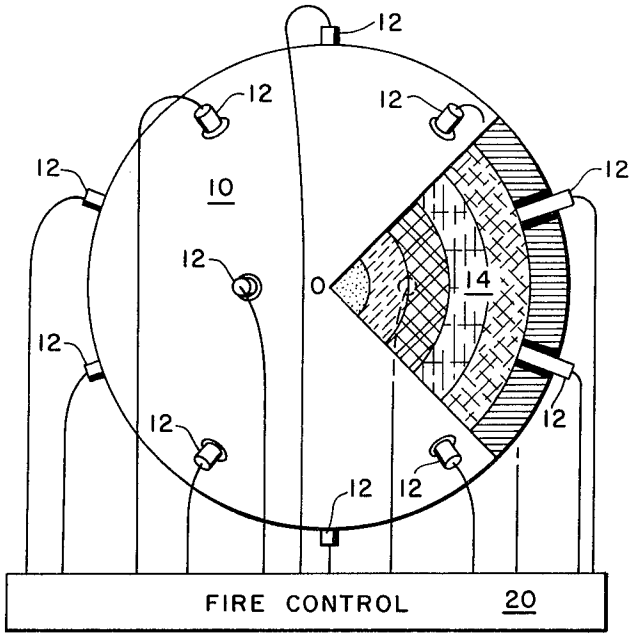


FIG. 1

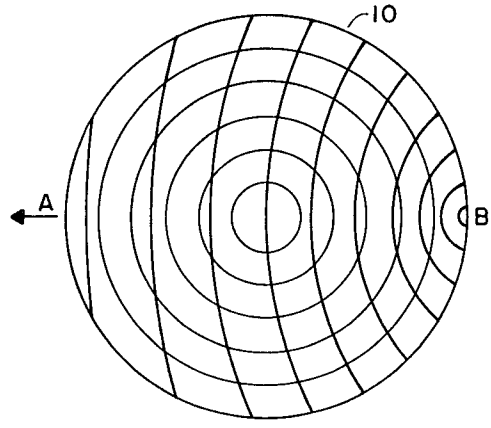


FIG. 2

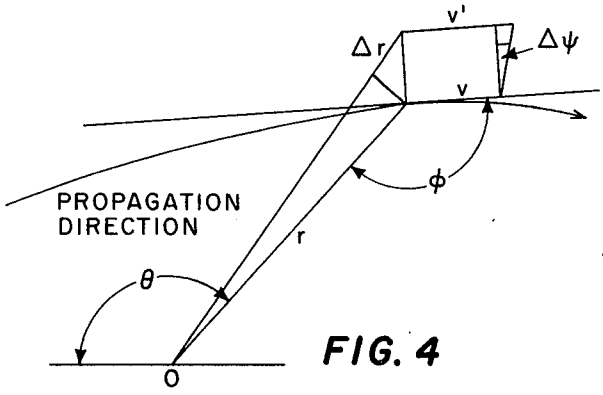


FIG. 4

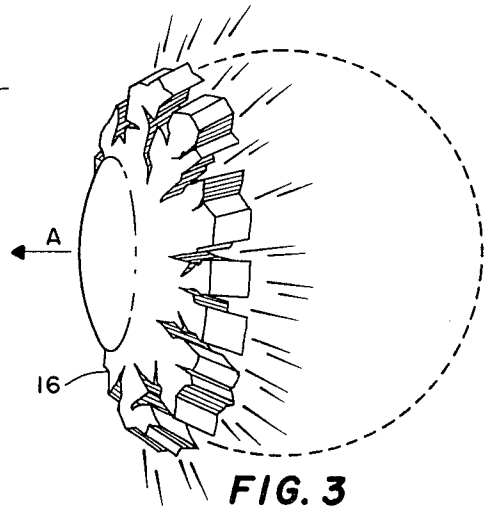


FIG. 3

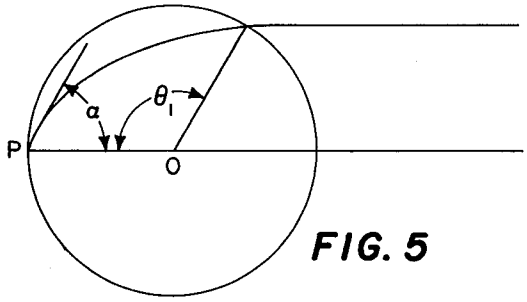


FIG. 5

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EXPLOSIVE LUNEBERG LENS WARHEAD

The invention herein described may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

The present invention relates to fragmentation or blast warheads and the like, and more particularly to an explosive aimable warhead.

This invention is related to copending Application Ser. No. 524,352, filed Feb. 1, 1966, for Explosive Fisheye Lens Warhead.

Fragmentation warheads currently used on guided missiles produce a fragment pattern, when the warhead is detonated, that is either spherically or cylindrically symmetric about the warhead. Although the transfer of energy from the explosive to the fragments is efficient, only a small fraction of the fragments will intercept the target, assumed to be airborne, and therefore the overall efficiency of this type of warhead is low. A greater efficiency would be obtained if most of the fragments were directed toward the target. A warhead that has this capability is called an aimable warhead.

Aiming is difficult because of the inability to determine, until a few milliseconds before the warhead is detonated, on which side of the target the missile and warhead will pass. Thus, in a period of a few milliseconds, the warhead must be pointed or aimed at the target and detonated. In this short time it is difficult to aim the warhead by moving it, because the inertia of the warhead makes it difficult to rotate it into the proper position sufficiently fast to hit the target.

The present invention as hereinafter described is a system for an aimable warhead designed in the form of an explosive Luneberg lens. With detonators evenly spaced about its spherical surface or cylindrical surface, the warhead can be aimed and fired in any given direction by firing a detonator on an opposite side. Shock waves progressing through the warhead can detonate all the explosive in such a way as to develop a plane wave that propagates in the direction of aim. Equations are derived for the required detonation velocity as a function of radius, and explosives are selected with the proper detonation velocities for the desired sphere or cylinder size.

It is an object of the invention, therefore, to provide a warhead in the form of an explosive Luneberg lens.

Another object of the invention is to provide an efficient aimable warhead, detonatable in any direction.

A further object of the invention is to provide an explosive warhead in which the explosive when detonated develops a a plane wave in the direction of aim for propagating a concentration of fragments in the aimed direction.

Other objects and many of the attendant advantages of this invention will become readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 shows a typical spherical warhead, in the form of a Luneberg lens, with a plurality of detonators spaced about its surface.

FIG. 2 is a diagrammatic sketch showing progression of shock wave from point of detonation across Luneberg lens.

FIG. 3 illustrates how detonation of explosive Luneberg lens as in FIG. 2 develops a plane wave that propagates fragmentation of the warhead in a given direction, as aimed.

FIG. 4 illustrates the differential relationships for the bending of the direction of propagation of a shock wave passing through a sphere.

FIG. 5 illustrates the propagation direction of a shock wave in a Luneberg lens.

The system discussed here is for a spherically symmetric, fragmenting warhead which can be aimed in a given direction without moving the warhead. The warhead is in the form of an explosive Luneberg lens **10** and has a large number of detonators **12** evenly spaced about its spherical surface; any number of detonators **12** can be used as desired. To simultaneously aim and fire the warhead in any given direction A, FIG. **2**, it is only necessary to fire one of the detonators **12** on the opposite side of the warhead at B. Shock waves progressing from this chosen detonator through the warhead will detonate all the explosive layers **14** in the warhead in such a way that a plane wave which propagates in the direction of aim originates in the explosive to direct most of the fragments toward a target, as shown in FIG. **3.** The plane wave develops in this manner because the warhead device is constructed to focus detonation waves in the same way that the optical Luneberg lens focuses light. A fire control system **20** can determine the direction of aim, when and which detonator to fire.

The Luneberg lens (R. K. Luneberg, *Mathematical Theory of Optics*. Mimeographed Lecture Notes, Brown University, Providence, R.I. (1944), p. 213) is an inhomogeneous sphere with the refractive index given by the equation

$$n = \sqrt{2 - r^2} \qquad 0 \leq r \leq 1.0 \tag{1}$$

For a sphere of unit radius placed in a homogeneous medium of refractive index **1**, this lens causes a parallel light beam incident on one side of the lens to be sharply focused at a point on the opposite surface of the sphere or, conversely, the lens causes a point source of light located on one side of the lens to produce a parallel beam of light on the opposite side. The refractive index of a material is by definition the ratio of the speed of light in vacuum to the speed of light in the material. It is later shown in the derivation of equations for the explosive Luneberg lens that the detonation velocity in an explosive lens replaces the light velocity in the optical Luneberg lens. Thus, to produce an explosive Luneberg lens it is necessary to have the reciprocal of the detonation velocity in the explosive sphere expressed by Equation (1), which requires that the detonation velocity at the center of the explosive lens be $1/\sqrt{2}$ times the velocity at the periphery of the spherical lens. This difference in detonation velocity can be obtained easily. From M. A. Cook, *The Science of High Explosives*. New York: Reinhold Publishing Corp. (1959), p. 45., the detonation velocity of Composition C is 8,100 meters/sec and the propagation velocity of TNT is 5,010 meters/sec. The ratio of these two detonation velocities is greater than 2. Other explosives listed in Table 3.1 of Cook's text show detonation velocities intermediate between 5,010 and 8,100 meters/sec; thus it is possible to choose explosives which have the proper detonation

velocities for the explosive Luneberg lens. The lens might have as many as five concentric shells, for example, each of a somewhat different explosive composition, as shown in FIG. 1.

When small diameter, cylindrical, explosive charges are fired, the detonation velocity is a function of the diameter of the cylindrical charge. As the diameter of the charge is increased, the detonation velocity increases and approaches a limiting value asymptotically. The detonation velocities given in Cook's Table 3.1 are for explosive charges sufficiently large so that further increase in the diameter of the cylindrical charge produces no measurable increase in detonation velocity. In Cook's FIG. 3.4, in which he shows a detonation velocity as a function of charge diameter, it can be seen that the minimum diameter for maximum detonation velocity of unconfined TNT is about 4 cms. When the explosive is confined, the minimum diameter for maximum detonation velocity is decreased. In the explosive Luneberg lens, the adjacent explosive shells would decrease the minimum diameter for maximum detonation velocity to a value somewhat less that those shown in FIG. 3.4 of Cook. However, an explosive Luneberg lens would have a minimum size which, depending on the explosives used, might be of the order of 6 inches in diameter.

A second possible procedure for obtaining the required distribution of detonation velocities is by means of the effect of density on detonation velocity, as given by Cook in his Equation 3.1. This equation shows a linear relationship between detonation velocity and density. Detonation velocity is greater in high-density explosives than in low-density explosives. By using high-density RDX at the periphery of the sphere and concentric shells in which the RDX is mixed with an inert low-density material to decrease the average density of explosive, it is possible to produce the series of detonation velocities needed for the explosive Luneberg lens aimable warhead.

Luneberg lens calculations assume that the lens is surrounded by a medium of refractive index unity, which is also the refractive index at the surface of the spherical lens; therefore there is no discontinuity at the surface of the lens. Applied to the explosive Luneberg lens, this theory requires that the Luneberg lens be surrounded by a large, homogeneous, isotropic mass of explosive with a detonation velocity equal to the detonation velocity at the surface of the lens. In this case, as in the optical case, there is no discontinuity at the surface of the lens, and the shock waves propagate in the direction they were traveling at the surface of the lens. The actual warhead is surrounded by a spherical steel shell which in turn is surrounded by air. The shock wave velocity in air decreases and soon is well below the detonation velocity of the outer shell of the lens. Thus the shock waves proceeding from the warhead are not planar a short distance from the warhead; however, this is not too important because after the energy of the explosive has been transferred to the steel casing of the warhead, the interest is in the trajectory of the fragments rather than in the propagation of shock waves. These fragments will continue to travel in their initial direction until slowed by air resistance or encounter with the target. The trajectories will not be parallel but will diverge by a small angle, which is probably desirable because the divergence will make it easier to hit the target.

Conservation of momentum requires that if velocities are the same, the total mass discharged in the aimed direction of the warhead must be balanced by an equal mass driven in the opposite direction. The Luneberg lens warhead produces a dense beam aimed in the forward direction and a diffused fragment pattern in the backward direction.

The equations for the explosive Luneberg lens are derived here without any reference to optics.

The explosive lens is in the form of an inhomogeneous sphere. If the explosive is detonated at one point on the surface of the sphere and the shock wave at the other side is to be a plane wave, the propagation velocity of the shock wave must be larger on the outside of the sphere, for this shock wave must travel further in the same amount of time than a shock wave traveling through the center of the sphere. Since the propagation velocity is a function only of the radius of the sphere, lines normal to the shock fronts or parallel to the direction of propagation must lie in planes which pass through the center of the sphere. Such a plane is shown in FIG. 4 where 0 is the center of the sphere. Bending of the propagation direction will result from the propagation velocity being a function of radius. In FIG. 4 the propagation velocity at a point $r+\Delta r$ will be greater by a small increment than the propagation velocity at the point r. This difference in propagation velocity causes a curvature of the direction of propagation by an amount $\Delta\psi$.

From FIG. 4, by Taylor's expansion:

$$v' = v(r) + \Delta r\ (dv/dr) \tag{2}$$

By trigonometry

$$\tan \Delta\psi = (v'\Delta t - v\Delta t/\Delta r/\sin\Phi) = \sin \Phi\ \Delta t\ (dv/dr) \tag{3}$$

As Δt and $\Delta r \rightarrow 0$, this becomes

$$d\psi = \sin \Phi dt\ (dv/dr) \tag{4}$$

where $d\psi$ is the element of bending of the propagation direction. Since (from FIG. 4) $dr/dt = v \cos \Phi$, Equation 4 can be written as

$$d\psi = dv/v \tan \Phi \tag{5}$$

The change in Φ or $\Delta\Phi$ will be the difference between $\Delta\psi$ and the change in θ or $\Delta\theta$. From FIG. 4

$$\tan \Delta\theta = (v\Delta t \sin \Phi)/r \tag{6}$$

As $\Delta t \rightarrow 0$ this becomes

$$d\theta = v \sin \Phi dt/r \tag{7}$$

and from Equations 4 and 7

$$d\Phi = \sin \Phi dt\ (dv/dr) - (v \sin \Phi dt/r) \tag{8}$$

Since $dr/dt = v \cos \Phi$, Equation 8 can be written as

$$d\Phi = \tan \Phi\ dv/v - \tan \Phi\ (dr/r) \tag{9}$$

Division by tan Φ and integration give

$$r/v \sin \Phi = k \tag{10}$$

where k is the constant of integration.

We will consider propagation curves starting at a point P on the surface of the sphere of radius $r = 1$ and passing through the sphere and on beyond it to a second point at infinity, as shown in FIG. 5. The propagation velocity outside the sphere is assumed to have a value of unity, which is also the propagation velocity at the surface of the sphere. The propagation velocity inside the sphere is less than one. A particular propagation curve from P will make an angle α at P with a line passing through the center of the sphere. From Equation 10, since the propagation velocity equals one at the surface of the sphere where $r = 1.0$,

$$\sin \alpha = k \tag{11}$$

The point where the propagation curve leaves the sphere is $r = 1$, $\theta = \theta_1$. At the angle $\theta_1/2$, $\Phi = \pi/2$, and therefore Equation 10 reduces to

$$r/v^* = k \tag{12}$$

where v^* is the propagation velocity at $\theta_1/2$. From Equations 5 and 10, by eliminating Φ, we can derive the equation for the bending of the direction of propagation,

$$d\psi = (k\, dn)/(n\ \sqrt{n^2r^2 - k^2}) \tag{13}$$

where $n = 1/v$.

The total angle of bending is α and, from Equation 11, $\alpha = \sin^{-1}k$. At $\theta = \theta_1/2$, half the bending has taken place and $v = v^*$. Thus, from Equations 11 and 13, the total bending is given by

$$2\int_1^{n^*} \frac{k\,dn}{n\sqrt{n^2r^2-k^2}} = \sin^{-1} k \tag{14}$$

where $n^* = 1/v^*$.

It can now be shown that Equation 14 is satisfied by

$$n^2 = 2 - r^2 \tag{15}$$

When Equation 15 is substituted into the left side of 14, it can be integrated to give

$$\sin^{-1} (n^{*2}-k^2)/(n^{*2}\sqrt{1-k^2}) - \sin^{-1}\sqrt{1-k^2} \tag{16}$$

From equations 12 and 15, with $n^* = 1/v^*$,

$$n^* = 1 + \sqrt{1-k^2} \tag{17}$$

and

$$(n^{*2} - k^2)/(n^{*2}\ \sqrt{1-k^2}) = 1 \tag{18}$$

so that Equation 16 becomes

$$\pi/2 - \sin^{-1}\ \sqrt{1-k^2} \tag{19}$$

Taking the sin of 19 gives

$$\sin(\pi/2 - \sin^{-1}\ \sqrt{1-k^2}) = \cos(\sin^{-1}\ \sqrt{1-k^2}) = k \tag{20}$$

Thus the left side of Equation 14 reduces to $\sin^{-1}k$, which shows that 15 is a solution of the integral equation 14.

It is now apparent that this invention will make guided missile warheads more effective since the warhead can now be aimed (i.e., exploded) in any particular desired direction irrespective of the direction the missile is traveling.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. An aimable explosive warhead operable to be aimed without moving the warhead and fired in any given direction, comprising:

a. an explosive Luneberg lens warhead constructed in the form of an inhomogeneous sphere,

b. the Luneberg lens warhead having an outer spherical warhead fragmentation casing,

c. the spherical warhead casing being filled with explosive, said explosive consisting of several concentric spherical explosive shells each of somewhat different explosive composition and having different detonation velocities, the detonation velocity of explosive at the center of said explosive lens being $1/\sqrt{2}$ times the detonation velocity of explosive at the periphery thereof,

d. a large number of detonators evenly spaced and mounted about the spherical surface of said Luneberg lens warhead,

e. fire control means for selectively firing any of said detonators upon command,

f. said warhead operable to be aimed in any direction by said fire control means by selectively firing a detonator on the opposite side of the warhead from the desired direction of aim,

g. said warhead upon detonation of any one of said detonators operable to cause detonation waves to be focused and progress from the point of detonation through the warhead detonating all the explosive therein such that a plane wave is developed which propagates concentrated explosive force in the focused direction of aim to direct a dense beam of warhead casing fragments in said direction of aim.

2. A warhead as in claim **1** wherein the adjacent explosive shells are each of different density.

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