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INVESTIGATION OF THE PROBABILITY OF HITTING WITH BOMBS TIED TOGETHER

by

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Abstract

Ten files of the National Inventors' Council concerning bombing with cable connected bombs are examined and three of them are studied in detail. The latter seem to offer reasonable chances of success provided certain technical difficulties are overcome. Simple experimental procedure for testing two of the proposals are discussed.

Introduction.

The ten files of National Inventors' Council suggestions sent on 21 May 1943 by the Office of The Chief of Ordnance to the Ballistic Research Laboratory for examination contain a number of related proposals concerned with hitting a target with bombs, depth charges, mines, or torpedoes tied together with cables. These suggestions fall into two groups. One group proposes a train of bombs, one behind the other, connected by cables, which will strike at intervals on approximately the same spot and thus have a very great penetrating power. The second group of suggestions deals with the question of dropping over or in front of a target, such as a ship or a submarine, a cable or network of cables with bombs fastened at the end, in the hope that although the bombs may miss at first, the cables will draw them into contact with the sides of the ship, where they can do great damage. Tt is the second group of suggestions which will be discussed first.

Hitting with two torpedoes tied together.

George Baxter, of Marion, Kansas, has submitted a suggestion for a bomb to contain two torpedoes connected by a bouyant cable. This bomb is to be dropped in front of a ship, whereupon it comes apart, and the two torpedoes travel in opposite directions perpendicular to the path of the ship until the cable is tight. The ship, if unable to change its direction sufficiently rapidly will run into the rope and the torpedoes will be drawn into the sides of the ship, where they will explode.

There are a number of obvious technical objections to the proposal. Several of these are contained in the following paragraph quoted from the reply to the inventor from the Naval Bureau of Ordnance:

"Returned. Torpedoes running on the surface, as these would have to run, would place their charges so close to the waterline as to be ineffective against well-protected ships. The device described would necessarily have to be very bulky and heavy, extremely difficult to use from an airplane. If the connecting cable were buoyant through its length, it would have to be very thick and cumbersome. If it had floats along it at intervals it would be difficult to have it carried on a reel. The leaf springs would be a very unsatisfactory device for pushing two torpedoes out from the carrier. Some very special design would be needed for an exploder mechanism sufficiently sensitive to function against a ship but able to resist the shocks of water impact and the jolt which it would experience at the time the connecting cable became fully extended. There would be no good assurance that the connecting cable would extend itself across the line of the ship's advance, and there seem no provisions for insuring that the torpedoes would run straight."

Some additional comments may be added to several of these objections, particularly that having to do with the directions in which the torpedoes travel after impact. If the bomb is dropped from any considerable altitude, it will strike the water at an angle not close to horizontal unless it is provided with large wings which appears undesirable on several counts. If the bomb strikes nearly vertically, rotation of the bomb about its axis causes errors in the directions in which the torpedoes are supposed to travel. Even if the bomb strikes with its axis horizontal and in the proper direction, it has a large speed and the effect of the resistance of the water on the torpedoes while they are making a sudden 90 degree turn and during the early part of their paths makes it extremely difficult to predict their eventual directions. It is also doubtful that these would be the same from one occasion to the next.

It may be added that presumably after the torpedoes come to the ends of their ropes they remain still. Unless they are very close to the ship this gives it an excellant opportunity to change course and avoid the cable, operate some device on the front of the ship to cut the cable, or to destroy the motionless torpedoes by gunfire.

Certain, but not all, of these objections can be met by making alterations in the method in which the torpedoes are used. Suppose, for example, that the two torpedoes are launched in the regular manner from a side-by-side position from an airplane flying at low altitude toward the ship and from the front.* The two are connected by a cable which unwinds equally from each of them. The stabilizers are set so that each torpedo points outward slightly from the direction in which they were launched. They can be set to travel under the surface. As they travel, they separate, stretching the cable between them until it is all out, after which they will remain a constant distance apart and travel in the direction in which they were originally launched until the cable strikes the ship. Their speed and that of the ship will cause them to be drawn to the sides of the ship.

This method appears to eliminate the difficulties of launching and establishing the directions of the torpedoes. A principal objection is, however, that a cable of the required length and strength may very well have such a large drag as to slow the torpedoes almost to a standstill.

In order to make a very rough estimate of the effect of the cable on the motion of the torpedoes, let the motion be considered after the cables, of length 2ℓ, is all unwound. Let the y-axis be in the direction of the motion of the airplane at the instant of release, and the x-axis in the perpendicular direction. Symmetry of the cable with respect to the y-axis is assumed. Figure 1 depicts the axes, cables, and torpedoes at any time t.

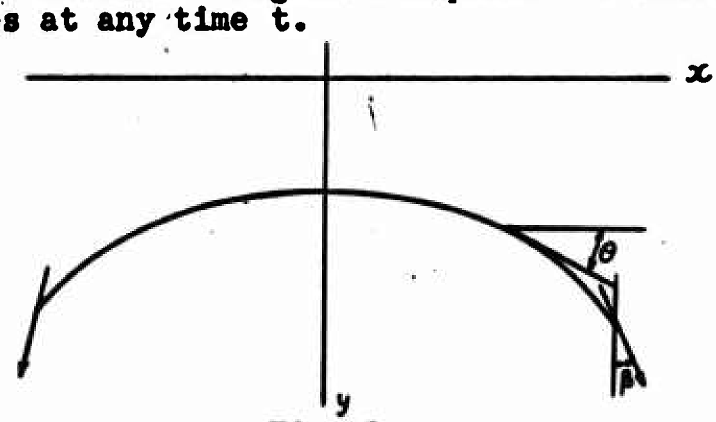

Fig. 1

For this analysis the forces of gravity will be ignored. This, of course, would be justifiable only if the cable and torpedoes have the same density as the water; however, it is to be hoped that the hydrodynamical forces are of the major consequence.

A small section of the cable of length ds will now be con-

* There may be a tactical advantage in this. Presumably more guns could be brought to bear on an airplane approaching from the side, from which torpedo attacks are usually made because of the larger target presented.

sidered. Let T be the tension in the cable and p its linear density. About the hydrodynamical forces some assumptions will have to be made. As in Figure 2, Fx and Fy are the x and y components of the hydrodynamical force F acting on ds. These forces are functions of the velocity; however, in the present case the velocity in the x-direction is small compared to that in the y-direction, consequently it will be assumed that they are functions of $\left(\frac{\partial y}{\partial t}\right)$. When $\theta = 0$, i.e., when the cable is perpendicular to the direction of motion, Fx = 0 and Fy is known, having been experimentally determined.

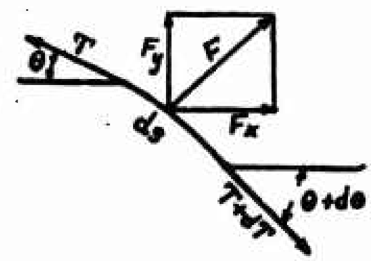

Fig. 2

In this case Fy has the form $C_D \cdot 1/2\ \rho v^2 d\ ds$ where C_D is a dimensionless coefficient which varies with the velocity v, ρ is the density of water and d is the diameter of the cable. When $\theta = 90°$, Fx is again zero, having been positive between zero and 90°; Fy on the other hand has decreased to a minimum which is not zero. Graphically, Fx and Fy are represented in Figure 3.

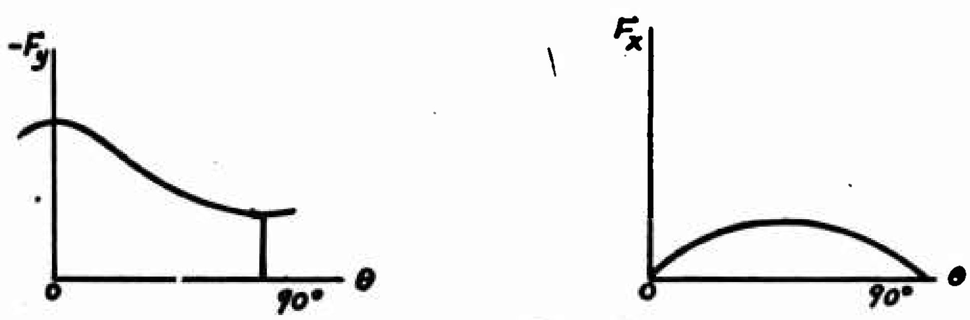

Fig. 3

This type of behavior can be described by the equations

$$
\begin{aligned}
Fy &= -k_1 (\cos^2\theta + \alpha)\, v^2\, ds\,, \\
Fx &= k_2 (\cos\theta \sin\theta)\, v^2\, ds\,.
\end{aligned}
\tag{1}
$$

The coefficient α appears to be small compared to 1, that is, the drag of the cable end on, is much less than broadside; Consequently α will be omitted in the present discussion. This is of little consequence except when θ is close to 90°, and it is assumed in the present case that the cable is more or less perpendicular to the direction of travel. Precise information is not available concerning the value of k_2, however; indications are that it is of the same order of magnitude of k_1 It shall be assumed then that

$$Fy = -k \cos^2 \theta \, v^2 \, ds \quad .$$
$$Fx = k \cos \theta \sin \theta \, v^2 \, ds \, . \tag{2}$$

Using the constant value 1.2 for C_D* and 62.5 for the density of water, it is seen that $k = 3.13d$ when d is the diameter of the cable in inches. Considering all forces (except gravity) acting on the element ds, then results

$$\frac{d}{ds}(T \cos \theta) + k \cos \theta \sin \theta \left(\frac{\partial y}{\partial t}\right)^2 = p \frac{\partial^2 x}{\partial t^2} \quad ,$$
$$\frac{d}{ds}(T \sin \theta) - k \cos^2 \theta \left(\frac{\partial y}{\partial t}\right)^2 = p \frac{\partial^2 y}{\partial t^2} \, . \tag{3}$$

The end conditions, at $s = \ell$, are determined by the motion of the torpedo. It will be assumed that the drag on the torpedo, assumed to weigh $M = 1000$ pounds, is λv^2 where λ is a constant; the value of λ assumed will be 12.5 which is approximately that for a 1000 pound bomb. In addition it must be recalled that the torpedo is yawing, and consequently there is a lift; a value of the lift force to correspond to the present case is $\mu \sin \varphi v^2$, when φ is the angle of yaw of the torpedo and $\mu = 125$. The end conditions are then

$$G \sin \alpha - (T \cos \theta)_{s=\ell} + \mu \sin \varphi \left(\frac{\partial y}{\partial t}\right)^2_{s=\ell} = M\left(\frac{\partial^2 x}{\partial t^2}\right)_{s=\ell} \quad ,$$
$$G \cos \alpha - (T \sin \theta)_{s=\ell} - \lambda \left(\frac{\partial y}{\partial t}\right)^2_{s=\ell} = M\left(\frac{\partial^2 y}{\partial t^2}\right)_{s=\ell} \quad ; \tag{4}$$

where G is the force exerted by the motor of the torpedo, and β is the angle between the axis of the torpedo and the y axis.

Let it be supposed that a stationary motion has been reached, that is, all accelerations are zero, $\left(\frac{\partial y}{\partial t}\right)$ is the same for all parts of the cable and the torpedo; and $\varphi = \beta$. Then

$$\frac{d}{ds}(T \cos \theta) + k \cos \theta \sin \theta \, v^2 = 0 \quad ,$$
$$\frac{d}{ds}(T \sin \theta) - k \cos^2 \theta \, v^2 = 0 \quad , \tag{5}$$

$$G \sin \beta - (T \cos \theta)_\ell + \mu \sin \; v^2 = 0 \quad ,$$
$$G \cos \beta - (T \sin \theta)_\ell - \lambda v^2 = 0 \quad . \tag{6}$$

* Diehl, Engineering Aerodynamics, p. 276

The first two equations have the solution

$$T = T_o = \text{tension at the center of the cable},$$

$$s = \frac{T_o}{kv^2}\int_0^\theta \sec\theta\, d\theta = \frac{T_o}{kv^2}\log(\sec\theta + \tan\theta).$$

In particular

$$\ell = \frac{T_o}{kv^2}\log(\sec\theta_\ell + \tan\theta_\ell),$$

or

$$T_o = \frac{kv^2\ell}{\log(\sec\theta_\ell + \tan\theta_\ell)}.$$

If this value is inserted into the equations (6) there results

$$G\sin\beta + \mu\sin\beta\, v^2 = \frac{kv^2\ell\cos\theta_\ell}{\log(\sec\theta_\ell + \tan\theta_\ell)},$$

$$G\cos\beta - \lambda v^2 = \frac{kv^2\ell\sin\theta_\ell}{\log(\sec\theta_\ell + \tan\theta_\ell)}.$$

Assume that G is sufficient to drive the torpedo alone at a speed of 50 miles per hour; in view of the drag of 12.5 v^2, G must amount to 67,500 poundals. Suppose also that ℓ = 100 feet and d = 1/4 inch. The two immediately preceeding equations give for any value of β the values of v and θ_ℓ. Since ds = dx cos θ, it is seen that

$$x_\ell = \int_0^\ell ds\cos\theta = \frac{T_o}{kv^2}\int_0^{\theta_\ell} d\theta$$

$$= \frac{\ell\theta_\ell}{\log(\sec\theta_\ell + \tan\theta_\ell)}.$$

This equation gives the value of x_ℓ for steady motion, where x_ℓ is one half the distance apart of the torpedoes. Table 1 gives several sets of corresponding values of x_ℓ, v, and β.

β	x_ℓ	v (ft/sec)
21.9°	91.5	28.1
4.9°	70.4	35.1
2.9°	57.3	40.4
.1°	32.7	48.2

Table 1

It must be borne in mind that there are a number of reasons why the quantities listed in Table 1 cannot be expected to agree very closely with the ones which would actually occur. In the first place, rather naive assumptions were made on the nature of the hydrodynamical forces acting on the cable and torpedoes. In the second place, the estimates of the size of the various coefficients involved are likely to be far from correct. On the other hand, the orders of magnitude of the distances and velocities in Table 1 are such as to make it seem quite plausible that an arrangement of two torpedoes with joining cable can be constructed and operated at a speed high enough to be worth while considering. For example, according to Table 1, two 1000 pound torpedoes each capable of traveling 73.4 feet per second with a drag of 12.5 v^2, connected by a 200 foot 1/4" cable can drag the cable at a speed of 40.4 feet per second at a distance apart of 114.6 feet, provided they are set at a yaw of 2.9°.

It does not appear that it would be difficult to test experimentally a device of this kind. It would only be necessary to equip two torpedoes with a cable and a means of reeling out the cable, and to provide a means of launching the torpedoes; for example, two stationary torpedo tubes mounted at an angle of 2 β to each other. For actual use, it would probably be necessary to provide a special type of fuse for the torpedos, since they presumably strike the ship broadside.

Hitting with cable connected bombs.

Mr. David Bannerman, of Manhasset, New York, has submitted a description of a bomb to be dropped from a high altitude on ships or submarines and constructed as follows: A case contains a cluster of four bombs, each provided with a reel and a length of steel cable, the four ends of the cable being joined at a point. After having fallen to a predetermined height, a time or barometric fuse causes the cluster to separate and the bombs to be thrown out to the extremeties of the cables, in four different directions, forming a pattern in the form of a cross. It is hoped that this pattern will fall so that either some of the bombs will strike the ship or the rope will fall across the ship or a short distance in front of it so as to be caught on the front of the ship. In these latter cases the bombs will be drawn by the motion of the ship to its sides where they will explode. The inventor suggests that they be equipped with a time fuse to delay the explosion until the bombs are in contact with the walls of the ship.

Before the ballistic aspects of the problem are considered, let the statistical aspects be taken up. In order to prevent the mathematical treatment from becoming excessively complicated, several simplifying assumptions will be made and definite numerical values assumed for the dimensions. The length of each cable will be 100 feet and the pattern across 200 feet each way. The ship will be 300 feet long and of zero width - an idealization of a long, thin ship such as a destroyer. The probability of a miss of less than 25 feet with an ordinary bomb will be compared with the probability of a contact hit with a bomb of the pattern; since these bombs would be smaller than the ordinary bombs, such problems would be the ones of interest.

Let the distribution function of probability of hitting be $f_Q(r)$ where Q is the point of aim and r is the distance from that point. This function will be assumed to be the same for both kinds of bombs although actually it would not be. Since the cluster would contain considerable empty space, it would be light and have a low ballistic coefficient. For the pattern bombing the intersection of the cables will be considered the point of impact.

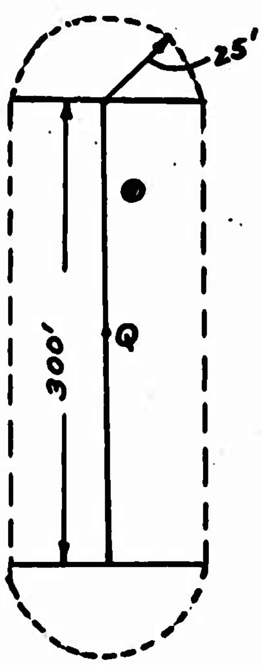

Figure 4

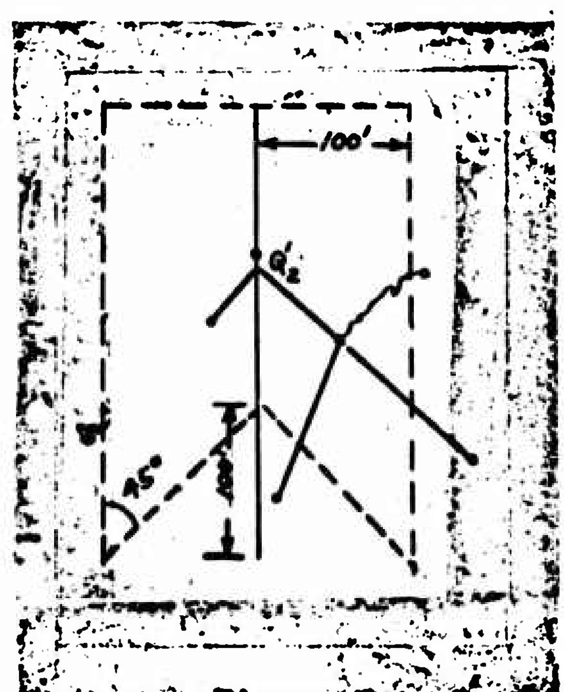

Figure 5

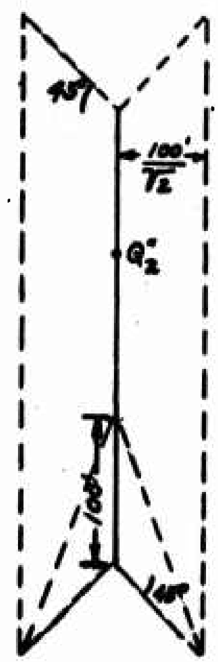

Figure 6

As can be seen in Figure 4, P_1, the probability of hitting within 25 feet of the ship with the ordinary bomb, is given by

$$P_1 = \iint_R f_{Q_1} dx\, dy$$

where R is the area within 25 feet of the ship and Q_1 is the center of the ship.

To compute the probability P_2 of a hit with the pattern involves a complicated problem in geometrical probability. However this can be greatly simplified by assuming that the cross lands with its axes either parallel to the ship or at 45° to the ship; these are the extreme cases, and the average of the probabilities computed in these two cases is not likely to be far from the true value.

Figure 5 shows the cross with its axes parallel to the ship. The area S' in which the center of impact can lie and cause at least one hit to be scored is marked with a dotted line. If the center of impact is ahead of this area, the bomb sinks, if it is to the left or right, the bombs miss the ship, while if it is behind, the bombs trail behind the ship and explode. The probability P_2' is

$$P_2' = \iint_{S'} f_{Q_2'} dx\, dy.$$

In this case it is obvious that Q_2 should be further forward than in the previous case.

Figure 6 shows the cross with its axes at 45° to the ship. The area S" in which the center of impact can lie and yet produce a hit is marked with a dotted line. The probability is of course

$$P_2'' = \iint_{S''} f_{Q_2''} dx\, dy.$$

As an example, suppose that f is constant over a circle containing the three figures R, S', and S" and zero outside. The probabilities are then proportional to the areas. These areas are 16,790, 50,000, and 45,400 respectively. Using $P_2 = 1/2\ (P_2' + P_2'')$ it is seen that P_1 and P_2 are proportional to 1.67 and 4.77 respectively - that is, one is 2.86 times as likely to obtain a hit with the pattern as a 25 foot miss with the single bomb. In a large part of the cases, the pattern will give two hits.

This discussion does not have for its purpose to attempt to prove that the bomb pattern is 2.86 times as effective as a single bomb. The relative effectiveness is dependent upon a number of factors including the dimensions of the ship and of the pattern, the construction of the ship, and the relative effectiveness of the two types of bombs at various distances. It is meant to point out the nature of the difference between the two methods of bombing, and the method will suffice to give more precise results in cases where the data are more accurately known.

The above statistical analysis has been based upon the supposition that perfect ballistic performance of the pattern of bombs is realized; that is, that on separation of the case the four bombs separate in four directions and at the moment of impact form the four vertices of a cross 2ℓ on a side, where ℓ is the length of each cable. There are, however, a number of reasons why this may not be easy to realize. The original bomb containing the cluster does not point or fall vertically unless it is dropped from a motionless carrier, and consequently when the four bombs are projected outward to the ends of their cables, they will not lie in a horizontal plane. Also their velocities have horizontal as well as vertical components, and one may well expect a complicated motion of the four bombs relative to one another, and not a simple dropping of the unit in the form of a cross.

If the bomb is dropped from a very high altitude and separated at a low altitude, it will be pointing close to vertical and have a velocity close to vertical when it separates, and the effect of the sidewise motion and the tilt of the plane of the bombs may be small. If it is neglected, one may consider the configuration of four bombs falling vertically downward. Taking a cross section through two bombs, this can be reduced to the two dimensional problem of two bombs falling vertically and connected by a cable of length 2ℓ. Choose x and y axes such that the x axis is horizontal and the y axis is vertical and directed downward through the center of the cable as in figure 7, symmetry about the y axis being assumed.

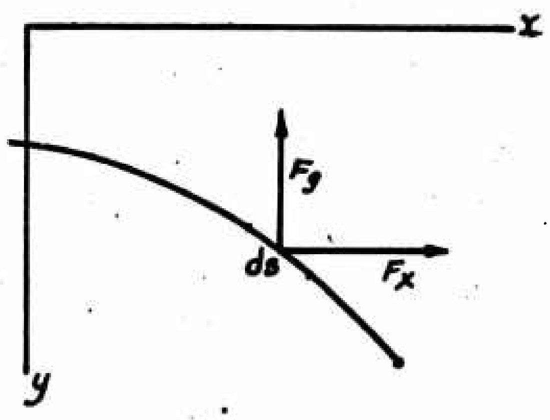

Figure 7

The aerodynamical forces acting on this cable are the same as those for the cable connecting the two torpedos discussed earlier in this report, and given by equations (1) except that the coefficients refer to air instead of water. Considering the forces acting on an element ds there results

$$\frac{d}{ds}(T\cos\theta) + k_2 v^2 \cos\theta\sin\theta = p\frac{\partial^2 x}{\partial t^2} \quad , \tag{7}$$

$$\frac{d}{ds}(T\sin\theta) - k_1 v^2(\cos^2\theta + \alpha) = -pg + p\frac{\partial^2 y}{\partial t^2} \quad .$$

The end conditions depend on what kind of bomb is attached. It is not possible as it is in the case of the torpedo to assign the direction of the forces acting on the bomb. The force of gravity is down. There is a sidewise aerodynamical force on the bomb if it is not falling vertically, but this is difficult to predict, because the direction in which the bomb points cannot be stabilized as can that of the torpedo. The proposer suggests that the fins on the bombs be set so as to pull the bomb away from the center and offset the tendency of the cables to pull the bombs together. It would be difficult to predict the behavior of such a system because little precise information is available concerning the aerodynamic forces on a bomb with unsymmetric fins. If the restoring moment M of the bomb with unsymmetric fins is $M(\delta,v)$, where δ is the angle of yaw, the lift is $L(\delta,v)$, and the drag is $D(\delta,v)$, then the end conditions are

$$(-T\cos\theta)_\ell + L(\delta,v) = M\ddot{x}_\ell \quad ,$$

$$(-T\sin\theta)_\ell - D(\delta,v) + Mg = M\ddot{y}_\ell \quad , \tag{8}$$

$$-I\ddot{\delta} = M(\delta,v) \quad ,$$

where I is the moment of inertia of the bomb about a transverse axis, and the cable is supposed attached at the center of gravity of the bomb. For a given arrangement of the fins, the moment, lift, and drag, could be determined experimentally and inserted into equation (8).

There are reasons to be dubious about the use of fin adjustments to keep the pattern spread apart in the manner outlined above. If, while the bomb is being projected outward from the case it acquires a small spin, the lack of symmetry in the fin will cause the bomb ~~to move~~ not outwards but in a direction to cause it to collide with the other bombs or to entangle the cables. Such information as is available leads one to suspect that bombs with bent fins are unpredictably erratic, and nothing short of experiment will make it known whether the arrangement proposed by the inventor will work.

Another possible way to keep the pattern from collapsing is to fasten the cables to the tail of the bombs. The pull of the cable will cause the bomb to tilt its axis and effect a sidewise force due to lift. Since this is an unaltered bomb, the drag, lift, and restoring moment can be taken in the usual manner as λv^2, $\mu v^2 \sin\delta$, and $\nu v^2 \sin\delta$ respectively. In terms of the customary aerodynamical coefficients, $\lambda = \rho d^2 K_D$, $\mu = \rho d^2 K_L$ and $\nu = \rho d^3 K_n$. The forces and moments acting on the bomb are depicted in Figure 8, and the end conditions are given in equations (9).

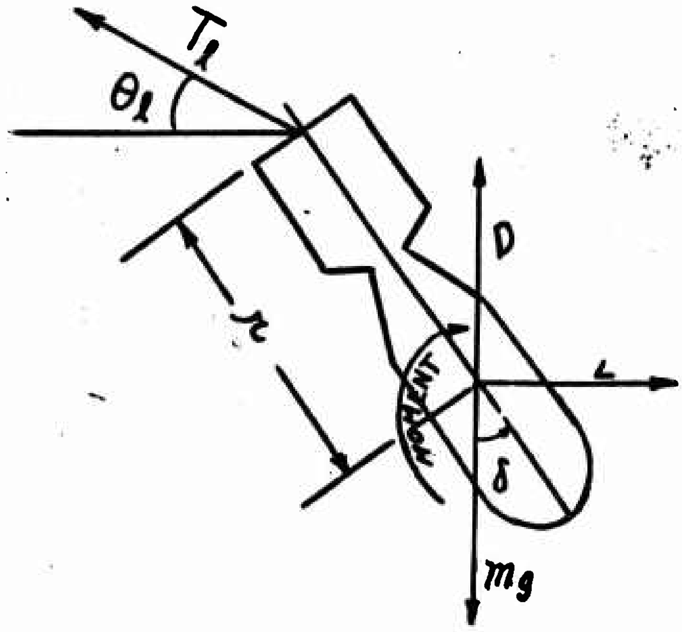

Figure 8

$$
\begin{aligned}
-(T\cos\theta)_l + \mu v^2 \sin\delta &= M(\ddot{x}_l + r\sin\delta) \\
-(T\sin\theta)_l - \lambda v^2 + Mg &= M(\ddot{y}_l + r\cos\delta) \qquad (9) \\
\nu v^2 \sin\delta - rT_l \cos(\theta_l + \delta) &= -I\ddot{\delta}
\end{aligned}
$$

With this set of end conditions it is possible to find all solutions giving steady motion; that is, all velocities constant. Equations (7) become in this case

$$
\begin{aligned}
\frac{d}{ds}(T\cos\theta) + k_2 v^2 \cos\theta\sin\theta &= 0 \quad , \\
\frac{d}{ds}(T\sin\theta) - k_1 v^2(\cos^2\theta + \alpha) &= -pg \quad .
\end{aligned} \qquad (10)
$$

By introducing $T\cos\theta$ and $T\sin\theta$ as new dependent variables and dividing the first of equations (10) by the second, a homogeneous equation results, and the system can be solved explicitly, the solutions being

$$T = \frac{T_0 \sec\theta}{(1+A\tan^2\theta)^{1/2B}} , \tag{11}$$

$$s = \frac{T_0}{k_2 v^2}\,\frac{A}{B}\int_0^{\theta} \frac{\sec^4\theta}{(1+A\tan^2\theta)^{\frac{1}{2B}+1}}\, d\theta,$$

where

$$B = 1 + \alpha\frac{k_1}{k_2} - \frac{\rho g}{k_2 v^2} , \quad A = B\Big/\left(\frac{k_1}{k_2} + \alpha\frac{k_1}{k_2} - \frac{\rho g}{k_2 v^2}\right)$$

In particular

$$\ell = \frac{T_0}{k_2 v^2}\,\frac{A}{B}\int_0^{\theta_\ell} \frac{\sec^4\theta}{(1+A\tan^2\theta)^{\frac{1}{2B}+1}}\, d\theta . \tag{12}$$

For a steady motion solution, equations (9) become

$$\begin{aligned} -(T\cos\theta)_\ell + \mu v^2 \sin\delta &= 0, \\ -(T\sin\theta)_\ell - \lambda v^2 + Mg &= 0, \\ \nu v^2 \sin\delta - r T_\ell \cos(\theta_\ell + \delta) &= 0. \end{aligned} \tag{13}$$

If T is substituted from equations (11) and (12) into equations (13), there results a set of three equations in θ_ℓ, v^2, and δ, which can be solved numerically.

It is of interest to note that there are two solutions for steady motion, at least for some values of the parameters, λ, α, k_ρ etc. Equations (13) have as a solution $\theta_\ell = 90°$, $\delta = 0$, $v^2 = Mg/\lambda$. But from equation (11) it follows that $B<1$; otherwise $T \to \infty$ as $\theta \to 90°$. This implies that $\alpha k_1 < \frac{\rho g}{v^2}$, or $v^2 < \frac{\rho g}{\alpha k_1}$ and finally $\frac{Mg}{\lambda} < \frac{\rho g}{\alpha k_1}$. In this mode of fall, the cable has assumed a shape which causes it to have the same terminal velocity of the bomb, and the tension on the ends of the rope is zero. The solution does not depend on the lift effect of the bombs and exists just as well for purely spherical bombs or mines or depth charges. It exists only if the terminal velocity $\sqrt{\frac{Mg}{\lambda}}$ of the bombs is less than the terminal velocity $\sqrt{\frac{pg}{\alpha k_1}}$ of the cable falling end on.

For a hundred pound bomb and quarter inch steel cable, these velocities are approximately 870 feet per second and 305 feet per second respectively, and it appears that for no combination likely to be used is this solution able to exist.

To obtain the solution which depends on the lift of the bombs, involves the solution of the rather complicated set of equations (11), (12) and (13). If the simplifying assumptions $p = \alpha = 0$, $k_1 = k_2$ are made, however, a numerical solution is not difficult. These are equivalent to assuming that the cable has no weight and no drag when traveling end on. Actually, the drag on the cable is so large compared to a bomb that assuming $p = 0$ may not cause much of an error. For quarter inch steel cable α is approximately 1/20, and hence if the rope is not too nearly vertical, the error in omitting it is not great. Using data suitable for a hundred pound bomb and quarter inch steel cable; $\lambda = .004$, $\mu = .04$, $\nu = .03$, $\ell = 100$, $k = .001$, $r = 2$, the solution is $\delta = 1.3°$, $\theta = 87.99°$, $v = 332$, $2x_\ell = 76.6$.

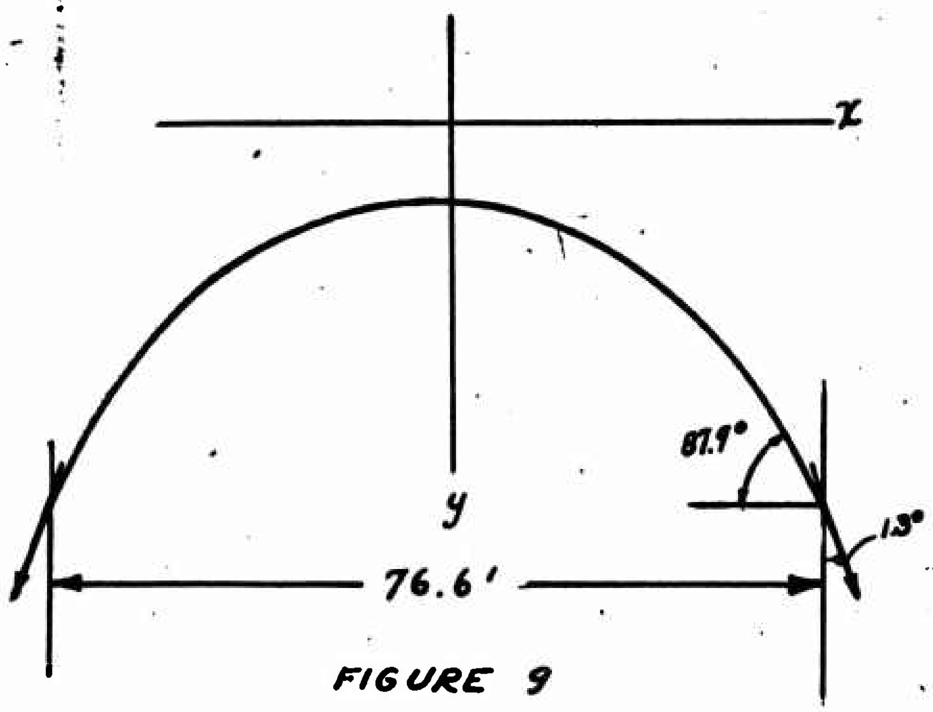

FIGURE 9

It is somewhat disappointing to note that the lift effect of the bombs is able only to keep the two ends separated by 76.6 feet out of a possible 200. To improve this figure one needs a bomb which has a high lift but small restoring moment, i.e. a nearly unstable bomb.

It appears from the foregoing discussion that it is likely to be difficult to keep the pattern of bombs permanently spread apart by fin or other adjustments on the bombs. A more likely method would be to equip the cluster with a fuze which causes the bombs to separate to their maximum spread only a short distance - say a hundred feet - above the target. The pattern would have not sufficient time to collapse before striking the target. This method has the additional advantage that throughout almost all of the trajectory, the bombs are encased, and consequently better ballistic performance can be expected than if they were separated throughout a considerable portion of the path.

It seems that if such a fuze could be provided, this proposal for bombing with clusters of cable connected bombs has a possibility of a moderate success at least. A considerable amount of care would have to be exercised in establishing the charge used to separate the cluster; if it is too small, the bombs do not separate in time, if too large, the cables may break or the bombs rebound and the cables tangle.

It is of interest to note that a similar device has been investigated by the British, for other purposes, however. The British mention a device consisting of a pair of bombs connected by a cable dropped on buildings in the hope of injuring vertical supporting columns. Presumably the theory is that the cable will hang on strong supporting members and cause the explosion to be near the member. Due to technical difficulties of launching and storage, however, the scheme has not actually been used.

Chain bombing.

M. Fugier, D.G. Edwards, J.J. McGrath, and K. Blyler and N. Reynolds have submitted almost identical proposals of bombing with a chain of bombs, one behind the other and connected by cables, so as to effect a greater penetration of the target. The theory of these inventors is that the first bomb shall strike the target, explode, and make a hole of a certain depth; the second shall enter the hole made by the first, and so on. If this occurs, penetration may be obtained which would exceed the penetration of a single larger bomb. This would obviously be a great advantage in attacking targets with several layers of protection armor, such as ships with several steel decks.

A primary difficulty, as has been pointed out in the replies to the proposers from the War Department, is that it is extremely dubious that the bombs will actually describe the same trajectory, one behind the other, and land on the same spot. Most of the proposers are aware that something must be done to cause this, and suggest bombs of increasingly large drag, or a drag plate at the end of the cable or on the last bomb. If this is done, it seems theoretically possible for the bombs to describe almost identical trajectories and stay almost in a straight line. However, in practice, there are excellent possibilities for other types of motion to occur. One of the main difficulties is that it would be impossible to launch the bombs so that initially they are in the desired configuration. Consequently the forces of interaction between the bombs at the start are rather unpredictable and one cannot be sure of their behavior. It is possible even that small differences in launching conditions of the bombs will cause the entire string to tumble or revolve about its center of gravity as it falls.

It must be remarked, however, that one cannot be sure that this undesired behavior will occur, particularly if a suitable launching arrangement can be devised. If the design of the bomb rack permits, as it does in the larger bombers, the best arrangement would probably be to launch the bombs simultaneously, one bomb being behind the other in a single row of the bomb rack. They would then lie initially in a straight line, but as small distances apart until the large drag on the last bomb causes the string to spread apart. If this arrangement is not possible then one might arrange the bombs one above the other or side by side and release them simultaneously. Their initial configuration would then be as in Figure 10, the bombs lying in a vertical or horizontal plane according as they were placed in a tier or side by side in the bomb bay.

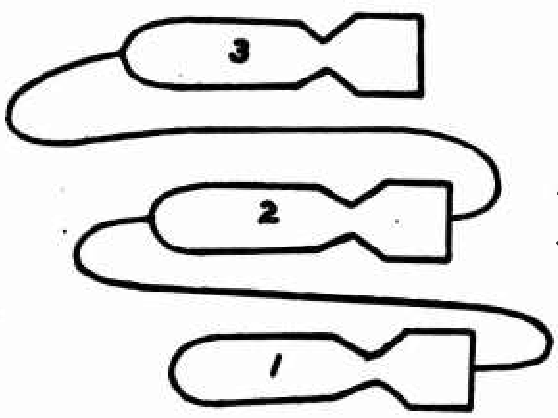

Figure 10

The No. 1 bomb having less drag than the others pulls ahead and below the others and starts the spreading out of the string to its maximum extent.

Let it be supposed that the configuration does not tumble or act erratically but that it begins, after launching, to spread out into a uniformly spaced sequence. At some subsequent time one may expect the sort of configuration exhibited in Figure 11, the motion being in the direction of the large arrow. Bearing in mind that the drag increase with the later bomb, it can be seen that then will be a moment exerted tending to rotate the chain in the clockwise direction.

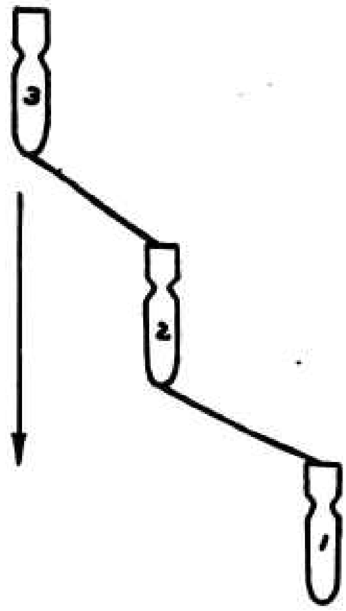

Figure 11

Likewise, the pull of the cables will cause the bombs to yaw, and lift effects will create a drift to the right. From this, it can be readily seen that oscillations and various kinds of sinuous motions of the chain can be expected if the configuration is ever disturbed from the position where all the bombs are pointing and traveling along the same trajectory. As for possible disturbing influences, one can mention in addition to those incident to launching, the effect of gusts of winds, of slight imperfections in the manufacture of the bombs, and of the natural yaws due to the curvature of the trajectory. To take an extreme case, if the drag of the last bomb is very large the motion would resemble that of a man hanging from a parachute.

To compensate partly for this tendency of the chain of bombs to vibrate, there exist also aerodynamical forces which tend to damp the vibrations. In order to see how these damping forces arise in the present case consider the problem in its simplest mathematical form; two spherical bombs of equal masses are connected by a dragless and weightless cable which is supposed kept tight. The drag on the upper bomb is μv^2 and on the lower bomb λv^2 where $\mu > \lambda$. The device is supposed to be falling vertically and performing small oscillations about its center of gravity.

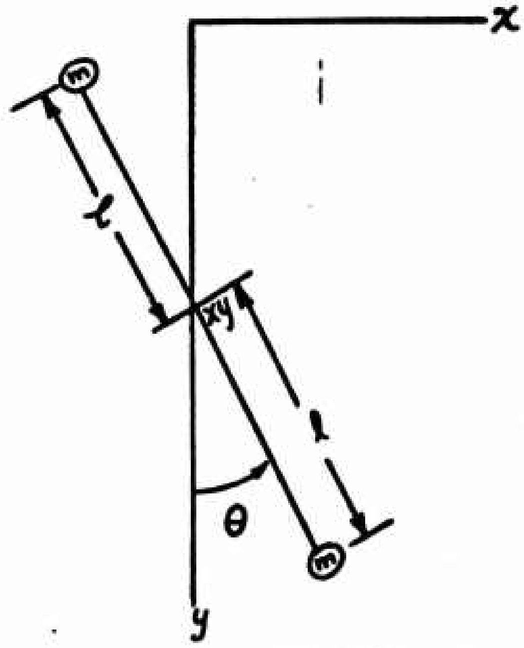

FIGURE 12

If Lagranges equations are put down and all terms of degree higher than one in θ, $\dot\theta$ and $\dot x$ discarded, there results the equations

$$2m\ddot x = -\dot x\dot y(\mu+\lambda) + \ell(\mu-\lambda)\dot y\dot\theta,$$

$$2m\ddot y - 2mg = -\dot y^2(\mu+\lambda),$$

$$2\ell m\ddot\theta = -(\mu-\lambda)\dot y^2\theta + (\mu-\lambda)\dot y\dot x - \ell(\mu+\lambda)\dot y\dot\theta.$$

The second equation can be solved explicitly and the other two become linear. It is not difficult to see that these represent damped oscillations of x and θ. Consider for example that the device is suspended in a wind tunnel, then $\dot y = v =$ constant and $\dot x = 0$. The last equation becomes

$$2\ell m\ddot\theta = -(\mu-\lambda)v^2\theta - \ell(\mu+\lambda)v\dot\theta,$$

which is a linear equation with constant coefficients representing damped oscillations.

From the foregoing discussion it appears that there are causes for oscillations in the chain of bombs, and also the possibility that if such oscillations occur they will be damped out. It would be of considerable interest to make an experiment to investigate the nature of the motion of such a chain, and would not be extremely difficult. A set of three or four bombs should be arranged in a bomb rack with connecting cables as shown in Figure 7, and released simultaneously. A motion picture record of the latter part of the trajectory would show whether the bombs were falling approximately in a straight line or swinging or yawing. By dropping over land, recovery of the bombs would show by just how much they failed to have the same point of impact.

Even though the bomb chain should function as it is hoped it is almost sure to be ballistically poor; that is, have a long time of flight, short range, and large dispersion. In addition the question of whether the first bomb, on exploding, will detonate the others in air or cause them to miss their mark is as yet unanswered.

Conclusions.

Three devices have been discussed in this report: Connected torpedoes, connected pattern of bombs, and chain of bombs. Fach of the three presents considerable difficulty in stowage and method of launching. The analysis of the motion of the connected torpedoes indicates that the device may very possibly be built to function as desired; however, the efficacy of the method would most certainly depend on the solution of numerous difficult technical problems. The success of the pattern bombing device would depend, for one thing, upon the development of a suitable case and fuze to cause the case to separate at the proper altitude above the target. It is unlikely to be successful from high altitudes, for such a cluster would necessarily make a light bomb and hence one with a large dispersion. There is little evidence from the theoretical study of the chain bombing proposal to expect that the device will function ballistically as predicted by the inventors.

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Ten files of the National Inventor's Council concerning bombing with cable connected bombs are examined. One group proposes a train of bombs, one behind the other, connected by cables, which will strike at intervals on approximately the same spot and thus have a very great penetrating power. Second group deals with dropping over or in front of a target, such as a ship, a cable with bombs fastened at the end, in the hope that the cables will draw them into contact with the sides of the ship. The latter seem to offer reasonable chances of success provided certain technical difficulties are overcome. Simple experimental procedure for testing two of the proposals are discussed.

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