AD-A018 427

CUMULATION OF EXPLOSIVE CHARGES

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12 November 1975

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FTD-ID(RS)I-2191-75

FOREIGN TECHNOLOGY DIVISION

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by

Ch. Schonefeld

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER FTD-ID(RS)I-2191-75	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) CUMULATION OF EXPLOSIVE CHARGES		5. TYPE OF REPORT & PERIOD COVERED Translation
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Ch. Schonefeld		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Foreign Technology Division Air Force Systems Command U. S. Air Force		12. REPORT DATE 1975
		13. NUMBER OF PAGES 9
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) 19		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

EDITED TRANSLATION

FTD-ID(RS)I-2191-75 12 November 1975

FTD-75-C-002388

CUMULATION OF EXPLOSIVE CHARGES

By: Ch. Schonefeld

English pages: 9

Source: Militärtechnik, Nr 3, 1975, PP. 114-116.

Country of origin: East Germany
Translated by: SCITRAN
F33657-72-D-0853
Requester: FTD/ETET
Approved for public release; distribution unlimited.

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CUMULATION OF EXPLOSIVE CHARGES

Ch. Schonefeld

The cumulation effect is one form of the highly directional explosive effect during the detonation of explosive charges which have a cumulative recess (funnel) along one of the faces.

The principle of cumulation can easily be explained with a simple example. A metallic sphere (Figure 1) drops from a certain height into a vessel with water. When penetrating the water surface, a cavity is produced behind the sphere, which collapses at a high rate, however. When a collision occurs between the water masses and the center of the cavity, a high pressure is formed which leads to expulsion of a water jet. The height of this jet can exceed many times the initial drop height of the sphere.

A similar phenomenon of energy concentration (cumulation) occurs during the detonation of explosive charges, which have conical, spherical, hyperbolic or other shaped recesses along one of the front surfaces. In experiments it has been determined that a thin metallic funnel insert considerably increases the explosive effect in the direction of the axis of the explosive charge. The cumulation effect during detonation of explosive charges with geometric front surface shapes has been known for over a hundred years, even though little attention has been given to it and for a long time no practical application could be found for it.

In the years 1923 to 1926, Sucharewski first made a systematic investigation of the cumulation effect. He was capable of finding a dependence of the explosive effect of the detonation products on the shape of the cumulative recess for the explosive charge. Only during the last few years of the 2nd World War did directed theoretical and experimental research work start in the area of the cumulation of explosive charges. These ended with the use of the hydrodynamic theory of ideal liquids for the physical and mathematical definition of the cumulation effect. Modern cumulation theory is based on the idea of Soviet and American scientists Lawrentjew, Prokowski, Tayler and Reichelberger.

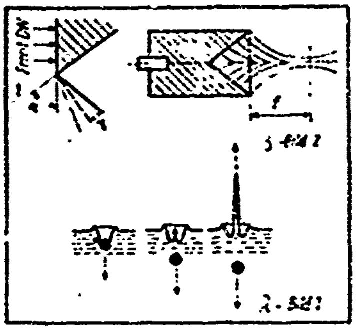

Figure 1. Principle of the cumulation effect.

Figure 2. Detonation diagram of an explosive charge with conical recess.

1- detonation wave front
2- Figure 1
3- Figure 2

Cumulative charges have wide applications in military technology in the form of effective weapons against armored targets. They are also applicable in industry, especially for oil transport and the explosive shaping of metals, as well as in experimental physics when highly ionized media are produced.

1. Cumulation effect and shaping of the hydrodynamic cumulative jet.

If the detonation is initiated at the face of the explosive charge, which lies opposite the cumulative recess, then the detonation wave front propagates to the surface of the cumulative funnel (Figure 2) after running through the peak with the angle α.

Experimental investigations show that the detonation products of the uppermost explosive layers are moved perpendicular to the funnel surface in the area of the cumulative funnel, and the greatest energy fraction (80%) is concentrated in a region of a relatively high angle. The bisector of this angle again has an angle γ with the normal to the surface of the cumulative recess, which depends greatly on α. For α = 45°-90° the angle γ lies in the limiting range between 9 and 15°.

The detonation products emerging from the funnel surface move in the direction of the funnel axis and form a beam, which has considerably higher density and motion velocity than the detonation products of the explosive charge, which propagates in other directions. This directed energy concentration of the detonation products is called the cumulative beam.

The detonation products have the maximum density at the narrowest ~~for~~ cross-section of the cumulative beam, the cumulative focus, which is located at a distance from the base of the funnel. A substantial increase in the directed explosive effect occurs only when the explosive charge is located at a distance from the obstacle in question which is not greater than the focal distance f.

The position of the cumulation focus depends greatly on the funnel shape and the explosive characteristics, such as detonation velocity, density, etc. The smaller the radius of curvature of the cumulative surface and the smaller the detonation velocity, the greater will be the distance of the cumulative focus from the base of the cumulative recess.

By the installation of so-called"lenses" in the charge body, it is possible to influence the position of the focus. These "lenses" consist of special materials or of explosives which produce a different detonation velocity. This makes it possible to control the detonation processes and provide for a simultaneous introduction of the detonation wave front into the various points of the surface of the cumulative funnel (Figure 3).

One special feature in the detonation of cumulative explosive charges is the fact that in order to form the cumulative beam only a small part of the total mass of the explosive charge is required. This explosive mass is called the immediate cumulative fraction (UKT) and is located in the region of the cumulative recess.

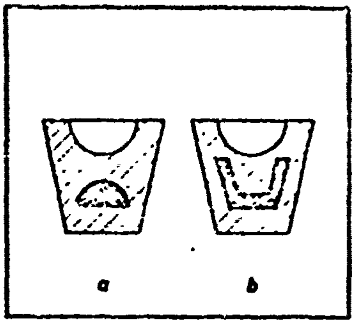

Figure 3. Cumulative charges with "inertial lenses." In case a, there is an "Adaptation" of the detonation wave front to the surface shape of the cumulative recess using a "lens" consisting of inert material; in example b, this is done by means of an explosive insert, which has a considerably reduced detonation velocity than the explosive of the cumulative charge itself.

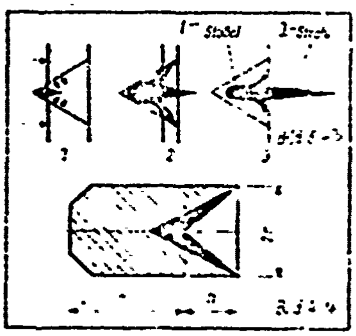

Figure 4. Direct accumulating part of the cumulative charge.

Figure 5. Schematic forming process of the cumulative beam.

1- Plunger
2- Beam
3- Figure 5
4- Figure 4

The mass of the UKT depends on the shape and dimensions of the charge, the cumulative recess and the explosive density. The UKT is a thin layer of explosive which becomes thinner in the direction of the cumulative funnel base. The mass of the UKT is calculated as follows for the cylindrical charge with the conical recess shown in Figure 4

$$m_{UKT} = \frac{5}{27} \pi \cdot h \cdot r^2 \cdot \rho_o,$$

h-depth of the cumulative recess, r-radius of funnel base, ρ_o - density of explosive.

The mass of the total charge is determined by the relationship

$$m_L = \frac{1}{3} \pi \cdot r^2 \cdot \rho_o \cdot (3a + 2h)$$

From the 2 relationships, we find the following for the relative mass of the UKT

$$\frac{m_{UKT}}{m_L} = \frac{5}{9} \cdot \frac{h}{3a + 2h}.$$

Calculations have shown that the minimum volume of a cylindrical charge with conical recess is obtained for a = 2h and 2r = 3/4 a.

For these conditions we have $\frac{m_{UKT}}{m_L} = \frac{5}{72} = 0.0695.$

This mean. that the active mass of the UKT is no more than 7% of the mass of the total charge.

The effective explosive effect can be increased if the surface of the cumulative recess is covered with a thin metallic insert, because part of the metal is used during the shaping of the cumulative beam. If the detonation wave front passes through the metal insert of the cumulative recess, then the metal particles are given a velocity pulse perpendicular to the surface. The magnitude of this velocity can reach 1000 to 1500 m/s depending on the explosive. Because of the extremely violent pressing processes, the metal insert is converted into a compact and monolithic mass, which is called the plunger. This phenomenon is accompanied by a large build-up of pressure (several million at). The metal of the insert starts flowing and forms a metallic cumulative beam with part of the detonation products. The mass of the metal which is converted to the cumulative beam is 6-12% of the total mass of the insert. The forming process of the metallic cumulative jet is shown schematically in Figure 5.

In the initial state of the formation process (1), the plunger and the beam are a single unit, even though their motion occurs with different velocities (plunger 1000 m/s, tip of the beam 10,000-12,000 m/s). After this the cumulative jet is torn away by the plunger and both decompose into individual parts. The effective destructive effect of the cumulative beam can only be achieved if the cumulative charge is located at a distance which makes impossible the decay of the beam.

The formation mechanism of the cumulative beam has been verified using modern spark-photography and roentgenographic methods and represents the practical foundation of the cumulation theory. Modern cumulation theory assumes that during the detonation process the metal insert overcomes the inertial forces which occur and the effect of all of the other bond forces of the metal structure can be ignored. Under these conditions the metal of the funnel insert behaves like an ideal liquid. The formation of the metal and the formation of the cumulative beam can therefore be compared with the process which occurred during the collision of beams of ideal liquids. The cumulation theory based on these ideas has been named the "hydrodynamic theory of cumulation."

2. Flow velocities and the impact on obstacles.

Within this paper it is not possible to derive the mathematical-physical relationships of this cumulation theory. We would only like to give the solution of the system of equations which occurs, which results in the flow velocities of the cumulation beam w_1 and of the plunger w_2:

$$w_1 = \frac{w_0}{\tan\frac{\alpha}{2}},$$

$$w_2 = w_0 \cdot \tan\frac{\alpha}{2}$$

w_0 is the velocity which is imparted to the elements of the metal insert because of the effect of the pressure of the detonation products. It is called the deformation velocity of the metal of the cumulative funnel insert.

The equations given above represent the general law of the cumulation effect and express the fact that the velocities of the beam and of the plunger are determined by the velocity at which the deformation process of the metal of the insert proceeds, as well as by the opening angle of the cumulative recess.

For $\alpha < \frac{1}{2}\pi$

we have $\frac{1}{\tan\frac{\alpha}{2}} > \tan\frac{\alpha}{2}$, i.e. $w_1 > w_2$.

Let us consider the process of the interaction of the cumulative beam and the material of a certain obstacle (metallic armor, etc.).

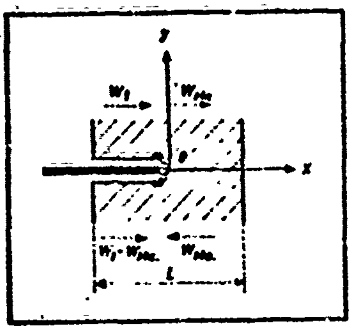

Figure 6. Schematic process of penetration of an armor plate with a cumulative beam.

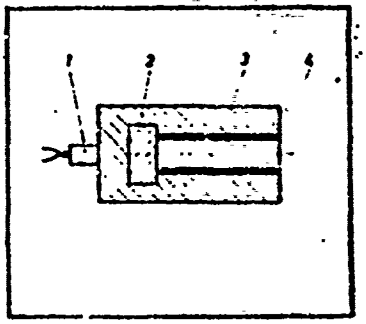

Figure 7. Structure of a cumulative charge with cylindrical shape of recess. 1- initiator charge, 2- inertial lens, 3- explosive (hexogens, Trotyl/Hexogens mixtures, etc.), 4- metal insert.

If the cumulation beam hits such an obstacle, then a structural change begins in the radial direction. The material of the obstacle starts flowing and as a result of this an opening is formed which is deepened at a certain velocity. Because of the extremely high motion velocity of the cumulative beam, the interaction process with the obstacle material can be considered as a flow process of ideal liquids and the hydrodynamic laws can be applied.

If it is assumed that the cumulative beam has the density ρ_1 and the length l_1 and the velocity w_1, then the material moves at the velocity w_{Ma} with respect to a coordinate system which moves with the point 0 to the left. Consequently, the cumulative beam moves to the right with the velocity $w_1 - w_{Ma}$ (Figure 6.).

Using the Bernoulli equation for ideal liquids ($P = \rho \cdot w^2 = $ const.) we obtain the expression

$$\rho_1 (w_1 - w_{Ma})^2 = \rho_{Ma} \cdot w^2_{Ma}$$

or

$$\frac{w_{Ma}}{w_1 - w_{Ma}} = \sqrt{\frac{\rho_1}{\rho_{Ma}}}$$

where ρ_{Ma} is the density of the material and $P_1 = P_{Ma}$.

The obstacle (armor plate) with a thickness of $L = w_{Ma}\ t$ is completely penetrated when the cumulative beam interacts with the armor plate during the time

$$t = \frac{l_1}{w_1 - w_{Ma}}$$

i.e., when

$$L = w_{Ma} \cdot t = \left(\frac{w_{Ma}}{w_1 - w_{Ma}}\right) l_1 = l_1 \sqrt{\frac{\rho_1}{\rho_{Ma}}}.$$

3. Ultra fast cumulation

In experiment physics, one important area of research is the production of media which move at velocities of several hundred kilometers per second. In order to bring about such velocities it is possible to either exploit strong electrical discharges or to use the methods of cumulation during the detonation of explosive charges. This leads to velocities which are similar to those of plasma motion.

If we analyze the general law of cumulation

$$w_1 = \frac{w_0}{\tan\frac{\alpha}{2}},$$

we can see that the velocity of cumulation beam increases as the opening angle α is reduced. If the velocity w_0 with which the process of deformation of the metal insert occurs is sufficiently large, then for sufficiently small values of α it is in principle possible to bring about relatively high velocities of the cumulation beam. In practice one uses cylindrical "funnel shapes" and in this case we speak of hyper fast or ultra fast cumulation. A number of papers by American scientists discuss the fact that cylindrical cumulative charges with metal inserts made of beryllium resulted in cumulative velocities of more than 10^5 m/s. Figure 4 shows the schematic structure of such a special charge.

During the detonation of ultra fast cumulative charges, a pressure of $1.5 \cdot 10^8$ kp/cm^2 and temperatures between 10^5 and 10^8 degres

Kelvin occurred in the region of the shock wave front, i.e., the cumulative beam medium can be considered to be a highly ionized gas (plasma) at the instant it collides with a fixed obstacle. In addition, it follows that under these conditions, cumulative beam values can be achieved which provide for not only a "penetration" action but also a "burning through" action with increased radiation.

7. Final conclusions and the future

The properties of the cumulative beam in general, and in particular its "penetration" effect at each target, depend not only on the opening angle of the recess but also on the material of the insert and its thickness. Relatively thick and even very thin inserts have a negative effect on the cumulative beam. In practice, metal inserts are used made of aluminum, special steels, copper, etc. with a wall thickness between 0.5 and 3 mm. The properties of the explosive have a great effect on the cumulative charge. The maximum cumulative effect is reached when explosives are used which have the largest density and the highest detonation velocity.

The cumulation makes it possible to direct the detonation phenomena in an effective way, makes it possible to produce a pressure and energy concentration within certain limits which can be substantially higher than the energy and pressure levels of the detonation products of the explosive itself. The cumulation is therefore an interesting area of research in the scientific and practical sense, which will undoubtedly produce more interesting results during the course of its development.