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CRLR 278
Project 4-04-15-007

INTERIM REPORT

FEASIBILITY OF DISSEMINATING CW AGENTS BY MEANS OF THE VORTEX RING PRINCIPLE

by

Henry Schwartzberg

This is an interim report. It is issued to transmit needed data to authorized personnel as rapidly as possible. Its conclusions are tentative and are subject to revision.

CHEMICAL CORPS
CHEMICAL AND RADIOLOGICAL LABORATORIES
Army Chemical Center
Maryland

2 November 1953

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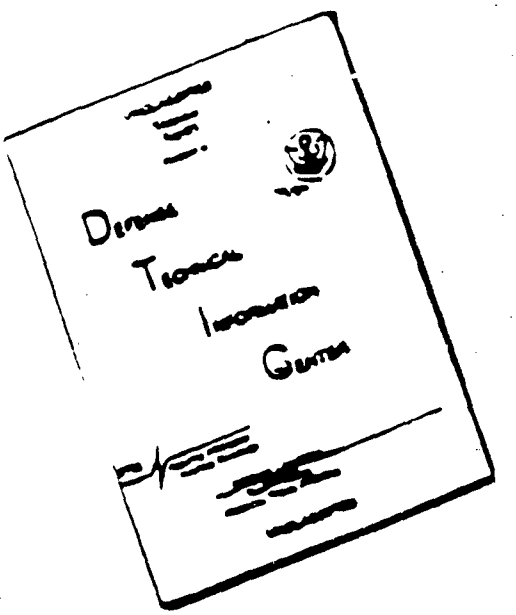

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CRLR 278
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INTERIM REPORT

FEASIBILITY OF DISSEMINATING CW AGENTS BY MEANS OF THE VORTEX RING PRINCIPLE

Submitted by:

for Milton Cutler
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Typed: 2 November 1953
ecc

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ABSTRACT

Object.

The object of project 4-04-15-007 is to investigate various means for disseminating solid and liquid toxic agents.

The object of the work described in this report was an attempt to confirm claims reported in intelligence documents relative to the military applications by Russian and German sources of the vortex ring principle for disseminating agents.

Results.

A literature survey revealed little information of a useful nature on vortex rings. Several formulae have been proposed to explain the behavior of vortex rings; however, there is insufficient experimental evidence to indicate which, if any, of the proposed relations are correct.

Limited experimental trials were conducted in an attempt to reproduce the equipment and results described in an intelligence report which described equipment and promising results on Russian experiments on the dissemination of agents by the vortex ring principle. Although a moderate number of combinations of design parameters were tried, no success was achieved in even approaching the range and accuracy claimed in the report. Caliber .30- and 20-mm. ammunition were used as the pulsing charges. While the report claimed ranges of the order of 300 meters, the ranges obtained in the experiments did not exceed 30 yd. The report claimed high aimability for the vortex rings, yet the aimability observed in the tests was found to be very poor and unpredictable.

Whether the failure of the limited tests reflects an inherent incapacity of this type of system for the useful field dissemination of CW agents or whether it was caused by a lack of understanding of the design parameters is a problem which can be resolved only after a prolonged period of fundamental hydrodynamic and aerodynamic experimentation. This was confirmed by an inquiry directed to an authority in the field of aerodynamics (see inclosure 1, appendix A). Though the failure of the systems tested does not preclude the possibility that the reported claims can be duplicated, it is indicated that a successful system would require a highly specific and precise design of unknown details.

It appears that the vortex ring principle, even if it could be made to operate in accordance with the claims of the Russian source, would not be competitive with conventional weapons for disseminating CB. There is a possibility that the vortex ring principle, if successful, may be practicable for projecting agents for riot control and possibly for projecting smoke agents.

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If the vortex ring were assumed to be one meter in diameter and if the ring were saturated with GB vapor, approximately 225 lb. of .30-cal. ammunition would be required to transport 10 lb. of GB.

Conclusions.

1. Attempts to reproduce the results claimed in an intelligence report relative to Russian experiments on the application of the vortex ring principle for the dissemination of agents were totally unsuccessful.

2. No basic information on vortex ring generation is available for guiding the design of a generator which would be substantially more efficient than the prototypes described in this report.

3. The vortex ring principle, even if completely successful, is inherently inefficient for the dissemination of GB.

4. If the claims made on the vortex ring principle could be substantiated, the most promising application may be the projection of agents for riot control.

Recommendations.

It is recommended that no further work be done on the application of the vortex ring principle for the dissemination of CW agents.

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TABLE OF CONTENTS

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FEASIBILITY OF DISSEMINATING CW AGENTS BY MEANS OF THE VORTEX RING PRINCIPLE

I. INTRODUCTION.

A. Object.

The object of project 4-04-15-007 is to investigate various means for disseminating solid and liquid toxic agents.

The object of the work described in this report was an attempt to confirm claims reported in intelligence documents relative to the military applications by Russian and German sources of the vortex ring principle for disseminating agents.

B. Authority.

Authority for this work was contained in CCTC item 1703, 26 September 1946 and the project program for fiscal years 1950, 1951, 1952, 1953, and 1954, Project 4-04-15-007, Dissemination of Solid and Liquid Toxic Agents.

II. HISTORICAL.

Prior to World War II, research on vortex ring producing devices had been carried out in Russia under the leadership of Prof. Tokmachev (Employment of War Gas - Professor Tokmachev's "Vortex Rings", ETF 550-810). Tokmachev succeeded in interesting Soviet military authorities in the project as early as 1937. Units or chambers, designed to be operated by the blasts emanating from a variety of military weapons, (infantry rifles, machine guns, and 76-mm. field guns) were built and tested.

It was hoped that these units would ultimately be capable of projecting with a high degree of aimability, and at high velocities, smoke or toxic CW agents in the form of vortex rings to relatively great ranges. In particular, Prof. Tokmachev thought that the units adapted for use with machine guns could ultimately be rendered capable of disseminating extremely great quantities of toxic CW at very rapid rates with a very high degree of efficiency.

Prof. Tokmachev was present at the early military experiments. In these experiments, according to Tokmachev, ranges of 300 meters, and ring muzzle velocities up to 114 meters/second were attained with rifles and machine guns. Vortex rings (1 meter in over-all diameter) were shot at a rate of 400 per minute from a Degtyarev machine gun. Tokmachev calculated that with ten machine guns, about one ton of war gas could be put out as vortex rings in four minutes. This was never experimentally substantiated.

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Tokmachev was not invited to witness the tests conducted with the 76-mm. field gun, and thus there is no available account of the results of this test. Although it probably did not give the expected results, Tokmachev had calculated that a ring muzzle velocity of 1300 meters/second could be obtained.

Due to the vagaries of Soviet politics the project was dropped after the test with the 76-mm. gun, and from then on only occasional interest in the project was shown by the military authorities.

In 1942, Tokmachev was captured by the Germans, and he put his ideas and services at their disposal. The Germans performed various tests the results of which (based upon inconclusive intelligence reports) largely confirmed Tokmachev's basic work. However, probably due to the demands of the War, the Germans were not able to continue their work, and there is no record of their adapting vortex chambers for use in existing military weapons.

It is from captured German accounts of these experiments, that our knowledge of Tokmachev, his history, and his work was derived. By the end of the war Tokmachev had disappeared.

III. THEORETICAL.

A. General.

The vortex ring may be illustrated by the cigarette smoke ring. It may be produced by generating a pulse of pressure or shock wave in an open mouthed vessel, the formation of the ring resulting from the interaction between the wave and the edges of the orifice through which it is emitted.

Generally the vortex ring takes the form of a toroid, all the elements of which are rotating about its circular axis and in a plane at right angles to that axis. The ring moves parallel to its central axis in the same direction that the inner surface is rotating (see fig. 1, appendix B).

Theoretical arguments based on an assumed medium of an ideal nonviscous fluid indicate that the vortex ring is a highly conservative entity, neither dissipating its internal energy, decreasing its velocity of translation, nor dispersing its contents. These implied properties suggest the potential utility of vortex rings as carriers of CW agent. However, in fact, the ring is somewhat slowed down, weakened, and subjected to the loss of its contents by the friction between it and the medium in which it is moving. Formulae have been evolved for the rate of decay of vortex rings in slightly viscous mediums, such as air, but they have not been experimentally confirmed.

One such formula as proposed by Tokmachev is as follows:

$$V = \frac{V_o}{(a.\ b.\ s.)^{3/2}}$$

where V_o = the muzzle velocity of the vortex rings
s = the distance
a = a constant dependent on the shape of the attachment
b = a constant dependent on the shape of the attachment

Then V is the velocity of propagation of the ring at any distance s from the source.

The Germans expressed contrary views, believing that the fall of the velocity of the ring is in the form of an exponential function.

Though the mathematical theory of vortex rings has been rather fully treated in the classical works on hydrodynamics and aerodynamics, only a limited body of experimental work has been recorded in the literature. In particular there is very little data as to how the geometric parameters of the vortex forming chamber affect the properties of the rings. Nor is there very much information correlating the characteristics of the blast or shock wave used to form the ring, with the properties of the ring.

The vortex forming chamber can be regarded as serving two functions. One is as a reservoir for the CW agent to be incorporated in a single vortex ring. To meet this requirement a certain minimum volume is required. The second function is to form and modify the flow pattern of the blast in order to produce that flow pattern which will give optimum properties to the vortex rings (i.e. maximize the capacity, contents, velocity, and range of the rings). A large size need not inherently be needed for this function, and perhaps the introduction of the proper baffles or flow forming shapes may permit a reduction in the size of the chamber.

Another problem on which very little information exists is, whether the vortex ring has the ability to carry internally an aerosol without centrifugally expelling the particulates making up the aerosol. This problem, which does not exist for gases, is of importance because of many CW agents which are most efficiently disseminated as aerosols.

B. Calculation of GB Propagation Using Vortex Rings.

1. Warm air when saturated with GB will contain approximately 20 g. of agent per cubic meter.

2. If we assume a vortex ring having a 1 meter diameter (Russian claim) then (volume = 0.1 cu.m.).

a. Each vortex ring could contain no more than 2 g. of GB.

b. It would require a minimum 22,500 such vortex rings to transport 100 lb. of agent.

c. If such a ring could be produced by a .30-cal. projectile, approximately 225 lb. of ammunition would have to be expended for each 10-lb. GB.

C. Calculation of GB Propagation Using a Short Range Conventional Munition.

If it is assumed that the 300-meter range claimed by the Russians to have been obtained with the vortex ring principle is reliable, it would appear desirable to compare its efficiency (225 lb. ammunition per 10-lb. GB) with that of another short range weapon such as a rifle grenade. The standard M19 rifle grenade (assuming it could be redesigned to contain GB) would consist of approximately one pound of metal components and 0.25 lb. GB. An expenditure of 225 lb. of metal components could therefore transport approximately 55 lb. GB by comparison.

D. Use of Vortex Rings to Disseminate CN.

Riot control operations are usually conducted at rather close range. Existing munitions such as the CN and CN-DM grenades are limited in their effectiveness since their inherent design makes it possible for them to be picked up and thrown back.

In this connection, CNB (CN dissolved in a solvent) was developed to be disseminated by a flame thrower. Consideration is also being given at the present time to the development of a generator to disseminate micropulverized CN. These methods of dissemination are not completely satisfactory in that the agent is released as a stream thus rendering the attacker nearly as vulnerable as the target personnel.

Vortex rings, on the other hand, are sharply defined and theoretically, can be expected to retain all of the agent within the rings during the greater part of their trajectory. This would be a distinct advantage over the methods outlined above. However, the large size generator required (indicated by the Russian claims) together with the anticipated effort and time required to obtain the necessary fundamental information leading to the development of such a generator do not appear to justify such a development.

IV. EXPERIMENTAL.

A. Equipment.

Several cylindrical test chambers, similar to those illustrated in fig. 2 were constructed. They were fitted on their front ends with changeable covers containing sharp edged circular orifices of varying diameters and were covered on their rear extremities by various types of membranes. The membranes consisted of rubber sheeting of various thicknesses and were in some cases overlaid by stiff disks of sheet plastic. These chambers could be filled with tobacco smoke or NH_4Cl smoke which could be projected in the form of rings by tapping the membrane in the back of the chamber.

Three pear-shaped test chambers designed to be operated by the blast emanating from a rifle or field gun were constructed. These are illustrated in figs. 3, 4, and 5, appendix B. The smaller two were designed to be operated with the M-1 rifle, and the larger one could be operated

either in conjunction with the M-1 rifle or with a modified 20 mm. gun.

The large chamber roughly corresponds in dimensions and shape to one of the reportedly successful German chambers. Externally, both smaller chambers are scaled down versions of the larger chamber.

These chambers were filled with NH_4Cl smoke or HC smoke prior to functioning, so that (when produced) the vortex rings would be rendered visible by the incorporated smoke.

Blank .30 caliber cartridges and .30 caliber rifle grenade cartridges were fired in the M-1 rifle to pulse the vortex chambers. Special, wood plugged, 20-mm. cartridges containing either 15, 20, and 25-g. charges of .30 caliber propellant powder were fired in the 20-mm. gun.

B. Procedure.

The cylindrical chambers were filled with smoke, the diaphragms tapped, and the range to which smoke rings were projected for various size orifices noted.

The diaphragms on the backs of the chambers were changed. Thicker diaphragms, thinner diaphragms, and diaphragms overlaid with stiff plastic plates were fitted on the chambers, and the range to which smoke rings were projected was noted.

Tests were run on the cylindrical chambers by filling them with smoke, tapping the diaphragm, and visually noting the distance to which the smoke rings were projected. This type of test was repeated for each of the various sized orifices, and for each type of diaphragm.

An additional method of determining the range was used. This consisted of aiming the chamber at a burning candle and noting the maximum distance at which vortex rings projected from the chamber would extinguish the candle.

The cylindrical chambers were filled with "Pyrofax" gas, aimed at a Bunsen flame, tapped, and the maximum distance at which the Bunsen flame would ignite the gas ring noted.

The small, pear-shaped chambers were attached by means of a clamp and a modified rifle grenade adapter to the end of an M-1 rifle (see fig. 3). The alignment was adjusted so that as far as possible the axis of the chamber was in line with the axis of the rifle barrel. Swabs soaked with NH_3 and HCl were deposited in the chamber, filling it with NH_4Cl smoke. Either a .30 caliber blank cartridge or a .30 caliber rifle grenade cartridge was inserted in the breech of the rifle. The rifle was fired and the range and velocity of the resultant vortex ring visually estimated. Sometimes to aid in this estimate, the assembly was aimed at light foliage, or at light, free hanging sheets of paper, and the maximum range at which the foliage or paper could be agitated by a vortex ring was noted.

The large pear-shaped chamber was fitted with a rack and bracket on which a rifle could be braced. A small HC (anti-dim can) grenade was ignited in the chamber filling it with $ZnCl_2$ smoke. The axis of the M-1 rifle barrel was aligned with the axis of the chamber. Either a .30 caliber blank cartridge or a .30 caliber rifle grenade cartridge was inserted in the breech of the rifle and the rifle was fired. The range and velocity of the resultant smoke ring were visually estimated.

The 20-mm. gun barrel was clamped in the bracket attached to the large chamber and was adjusted so that its axis and the axis of the chamber were aligned as closely as possible. A small HC anti-dim grenade was ignited in the chamber filling it with $ZnCl_2$ smoke. One of the special 20-mm. cartridges was inserted in the breech end of a 20-mm. gun barrel, and a special breech mechanism was attached, cocked and fired. The range, and velocity of the resultant smoke ring were visually estimated. An estimate, expressed as a percentage of the total smoke contents of the chamber, was made of that portion of the smoke which had been projected as part of the vortex ring. The test was repeated for each of the differently charged cartridges.

C. Results.

Smoke rings were projected from the cylindrical, membrane operated, chambers for distances up to 15 or 20 ft. Due to the variability of the results, it was difficult to detect differences in performance with respect to range for each of the various orifices, or for the various rubber membranes. It was noted, however, that the membranes backed by the stiff, sheet plastic disks were more efficient, easier to operate, and less critical in functioning than the plain rubber membranes.

In general the initial diameter of the smoke rings was about 1-1/4 to 1-1/2 times the diameter of the orifice from which they were emitted. The diameter of the ring tended to increase slightly as the ring traveled farther away from the chamber.

Candle flames were extinguished by vortex rings projected from cylindrical chambers up to 15 or 20 ft. away from the candle.

Vortex rings containing "Pyrofax" gas were inflamed in passing by a Bunsen flame located up to 15 ft. away from the cylindrical projection chamber.

Vortex rings were projected to ranges of approximately 35 ft. at speeds estimated to be about 30 ft./sec. by the action of the M-1 rifle blast passing through either of the two small, pear-shaped chambers.

No discernible difference in range or ring velocity was observed when the small chamber containing the interior baffle was substituted for the similar small chamber which contained no baffle.

Nor was any discernible difference in performance observed when .30 caliber rifle grenade cartridges were used in place of .30 caliber blank cartridges.

It was noted that it was extremely difficult to aim the vortex chamber unless its axis and the axis of the rifle barrel were very closely aligned. In all cases when aiming at light foliage it was difficult to get the ring to impinge against the foliage within five feet of the spot at which the rifle was aimed. In some cases, where there was more than a very slight misalignment in axis, the vortex rings hit ten or even twenty feet away from the spot at which the rifle was aimed. These errors occurred at ranges of approximately 35 ft.

In no case, when the M-1 rifle was used in conjunction with the large pear shaped vortex chamber were detectable vortex rings obtained.

In no case when the 20-mm. rifle was used in conjunction with the large pear-shaped vortex chamber were well defined vortex rings obtained. In all cases an irregular puff of smoke which did not travel more than ten feet were emitted from the chamber. However, in one case there was a sharp agitation of the light foliage thirty yards in front of the vortex chamber, such as had been experienced in other instances when vortex rings had impinged against foliage.

In every case, approximately 95% of the original smoke contents remained in the large pear-shaped chamber after a test shot had been fired, no more than 5% of the smoke escaping as part of the previously mentioned irregular smoke puff.

V. DISCUSSION.

It is apparent that the performances of these chambers did not confirm the claims of Tokmachev or the Germans. The maximum ranges obtained were less than 10% of the value of 300 meters which Tokmachev mentioned as being readily obtainable with infantry weapons. The ring velocities were less than 15% of the speed of 70 meters/second that he claimed as being most frequently obtained with infantry weapons and are slight compared to the 1,300 meters/second he anticipated as being obtainable with chambers of more advanced design. The aimability was very poor and unpredictable. The smoke carrying capacity of the vortex rings was markedly low. It is difficult to reconcile these differences. The poor aimability may have been due to misalignment of the chamber axis and the axis of the rifle barrel, or to the slight but unavoidable asymmetry of the hand-made vortex chambers.

The poor performance of the pear-shaped chambers with respect to ring ranges and velocities may have been due in part to certain gaps in the information available about the German chambers after which they were modeled. The approximate dimensions and over-all shapes were given, but certain facts, such as the relative positioning of the widest diameter of the pear shape, were not given in the basic report. This positioning had to be estimated, and the position decided upon may not have been the best.

Another factor about which there was relatively little information was the nature and type of blast most desirable for vortex formation. The Germans had mentioned that in certain chambers the weight of the blast charge might be critical. There is no information as to the most desirable type of pressure-time curve for any given explosive blast. It would seem apparent that the relatively slow pressure rise experienced with only partially confined black powder would not be desirable. But on the other hand, would the almost instantaneous pulse of pressure obtained from detonating tetryl represent the most desirable condition? It is obvious that, with the rifle and chamber type of system a high explosive charge could not be used.

Whatever the reasons, the fact remains that the performance of the field test vehicles did not live up to the claims made by Tokmachev.

Whether the failure of the pear-shaped chambers reflects an inherent incapacity of this type of system for the useful field dissemination of CW agents or whether it was caused by a lack of understanding of the design parameters is a problem which may be resolved only after a prolonged period of fundamental hydrodynamic and aerodynamic experimentation. Though the failure of the crude system tested does not preclude the possibility that systems of this type might be useful for the dissemination of certain CW agents, it does at least indicate that such systems do require a relatively refined and possibly precise design to make them usefully operative.

The basic report covering Tokmachev's work and that portion of this report dealing with the experimental work conducted at the Chemical and Radiological Laboratories were reviewed by Dr. Frederick W. Boss, a Chemical Corps consultant in aerodynamics. His review and conclusions are given in appendix A.

VI. CONCLUSIONS.

1. Attempts to reproduce the results claimed in an intelligence report relative to Russian experiments on the application of the vortex ring principle for the dissemination of agents were totally unsuccessful.

2. No basic information on vortex ring generation is available for guiding the design of a generator which would be substantially more efficient than the prototypes described in this report.

3. The vortex ring principle, even if completely successful, is inherently inefficient for the dissemination of CB.

4. If the claims made on the vortex ring principle could be substantiated, the most promising application may be the projection of agents for riot control.

VII. RECOMMENDATIONS.

It is recommended that no further work be done on the application of the vortex ring principle for the dissemination of CW agents.

APPENDIX A

Background and References

1. Discussion of Vortex Ring Formation and Propagation by Frederick W. Ross
2. Ltr. CMLRE-CR(M) to Technical Director, CRL, subject, Comments on "Vortex Rings" for Disseminating War Cases, 21 November 1951
3. Memorandum for File, 23 January 1952
4. Report of Test, 25 March 1952
5. Report of Test, 9 May 1952

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DISCUSSION OF VORTEX RING FORMATION AND PROPAGATION

After reviewing the report of Professor Tokmachev's work and the hand printed report, it appears the following points are evident:

(1) Tokmachev uses the equation (see p. 400)

$$V = \frac{V_o}{(abs)^{3/2}}$$

for the decay of velocity, V_o, with distance, s.

This formula is in agreement with that proposed by G. I. Tylor in (British) Advis. Comm. for Aero. London, R & M No. 598 (1918). This formula, however, is only one of a number which have been proposed. There is little experimental evidence available to indicate which, if any, of these several proposed relations are correct.

(2) In Tokmachev's relation cited above, as well as in all other similar relations proposed for showing the decay of velocity there appear constants — such as the a and b above. These constants are dependent upon the detailed shape of the attachment and its manner of operation, i.e. the constants are dependent upon the manner of formation of the vortex ring.

(3) In the Tokmachev report there appears to be no information given on the details of this manner of generation of the vortex rings. That is, the report does not divulge any important details regarding the relation between the magnitude of constants a and b and sufficient details of the attachments and their manner of use.

(4) On p. 401 of the Tokmachev report he uses the muzzle velocity of 3,000 m./sec. for the gases emanating from the muzzle of the cannon. This is about 10,000 ft./sec. and while it is the velocity obtained, presumably, from a blank firing, of which I have no information, it should be checked against available muzzle gas velocities to see if it is high or not.

(5) The use of the formula, $V_o/2.3$, implies a definite geometry for the ring. It implies a definite ratio between the diameter of the ring and the diameter of the core. For example, Lamb, "Hydrodynamics" p. 241 shows that the velocity of translation of the ring would be equal to the muzzle velocity, i.e., velocity at the center of the ring if the ring diameter is 86 times the core diameter.

This would be a very high velocity ring with a very thin core and consequently also of very little volume. Tokmachev's formula, $V_o/2.3$, implies some ratio of diameters which is high, but, of course, less than 86. The report does not say what it is.

(6) Again, the ratios of diameters, ring tocore, is determined by the manner of formation of the ring. This again then is determined by the detailed design and manner of operation of the attachments of which insufficient information appears to be given in the Tokmachev report.

Conclusions and Recommendations

The discussions given here and in the hand printed report both point up the fact that the Tokmachev report gives inadequate information on detail design and operation for the vortex ring generators (or attachments). The theory of generation and decay of vortex rings is complicated and has not been well substantiated experimentally. Inadequate information is available to determine definitely how to control such factors as ratio of ring to core diameter in terms of shape of attachment chamber and orifice and method of applying pressures, etc.

From general theory available there is no information to show that vortex ring velocities and distances of order of these claimed by Tokmachev cannot be approached. Yet the experiments described in the hand printed report show that if such is possible that adequate design information is not available for controlling the necessary vortex ring characteristics to obtain the greater distances.

From these conclusions then it would appear that if the project is to be pursued further it would be important to systematically study the details controlling the formation of vortex rings of different ratios of ring to core diameter.

Until such basic information is known, because of the complexity of the controlling factors, the chance of arriving at a design configuration that will give the higher velocities is very small. The experiments reported in the hand printed report are indicative of this.

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CMLRE-CR(M) Comments on "Vortex Rings" for Disseminating War Gases.

Technical Director | Chief, Munitions Division, Cml and Rad Labs | LONG/6175/mj, 21 November 1951

1. A study has been made of a summary of work that was accomplished by the Russians and Germans on the use of vortex rings for disseminating gases and smokes. Vortex rings may be formed by the action of a jet of propellant gases issuing from a gun and passing through a suitable fixture on the end of the gun barrel. If a gas to be disseminated is introduced into the fixture at the instant of discharge, the gas will be formed into a vortex ring which will travel in a straight line with very little dilution for a short distance, and will then break up. The maximum range attained has been approximately 400 yards.

2. Of the possible applications of the vortex ring method of dissemination, there appear to be three of interest to the Chemical Corps:

a. Dissemination of gases for mob control.
b. Projection of screening smoke.
c. Dissemination of toxic gases in close-up fighting.

3. For use as a means of mob control, where the release of a gas (lacrimator or sternutator) must be practically instantaneous and yet not involve fragments likely to produce permanent injury, the method might well be of value. The ability to direct the cloud with some precision would be an advantage in this case. Whether the leakage of gas at the device used to create the vortex rings could be kept low enough to avoid the use of gas masks is problematic.

4. The ability of a vortex ring apparatus to disperse considerable quantities of material suggest its usefulness in projecting screening smoke where a small area is to be obscured a short distance from the operator. The ability to place the smoke directly on the target with some accuracy and in a very short time might be of sufficient value to warrant the development of such a device to take the place of hand and rifle smoke grenades.

5. Due to its short range, the application of the vortex ring principle to the dissemination of toxic gas would require the use of a rapid-acting gas such as GB. This gas would not be safe to carry in storage containers which would necessarily have valves subject to leakage. HCN or CNCl might be useable since the necessary high concentrations at the target could probably be attained, while the low concentrations produced by leakage at the source would probably not be dangerous.

6. In view of the above considerations the vortex ring method offers the greatest possibilities in the dissemination of lacrimators, sternutators or screening smokes. Its usefulness in these fields would depend on the development of satisfactory gas containers and dispersing apparatus for use with hand weapons. It is desirable to make an investigation to determine the probability that such a development would constitute an improvement on the small munitions at present used for these applications.

7. A preliminary investigation and experimental work has been initiated.

C. B. DENNISON, Jr.
Colonel, Cml C
Chief, Munitions Division

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1 pink
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1 ARB
1 Mr. Long

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P
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MUNITIONS DIVISION
CML C CML & RAD LABS

Project 4-04-15-007
23 January 1952
SCHWARTZBERD/6122/mj

MEMORANDUM FOR FILE:

SUBJECT: Development Program Vortex Ring Devices

I. OBJECT

The object of the program described in this report is to determine the feasibility of dispersing, disseminating, or projecting CW agents by means of vortex ring producing devices.

II. AUTHORITY

The program will be ~~conducted under~~ the authority of project 4-04-15-007, X.O. 1271.

III. PURPOSE AND ADVANTAGES

In tactical situations where toxic CW agents can be used it is desirable that a high concentration of the agent be laid down on the target area within a given short period of time. By means of highly concentrated artillery, employed at very high rates of fire, it is often possible to achieve within a period of two minutes toxic gas concentrations capable of incapacitating enemy personnel who have not been sufficiently alerted as to put on their gas masks and other protective equipment.

It is hoped that, with relatively few vortex chamber-machine gun combinations, toxic gas concentrations sufficient to break down enemy canisters and incapacitate fully alerted enemy personnel can be achieved within an even shorter period of time.

Furthermore, since dispersion using a vortex system does not involve the concomitant use of shells, canisters, large propellant charges, or central burster charges, it should be far more efficient from a logistical point of view. In addition such factors as crater loss should be eliminated.

Vortex ring devices may prove to have a much more general applicability. Thus, by means of a vortex ring device it may be possible to lay down smoke screens on objects and areas some distance away from the smoke generator. There is also a possibility that they may be used to project inflammable gases to great ranges, thus making possible a long range flame thrower. In addition, the great shearing force generated in such rings may be used to accomplish some destructive purpose by itself.

IV. HISTORICAL

Prior to World War II, research on vortex ring producing devices had been carried out in Russia under the leadership of Prof. Tokmacher. Tokmacher succeeded in interesting Soviet Military Authorities in the project as early as 1937. Units or chambers, designed to be operated by the blast emanating from a variety of military weapons (infantry rifles, machine guns, and 76mm field guns) were built and tested. It was hoped that these units would ultimately be capable of projecting with a high degree of aimability, and at high velocity, smoke or toxic CW agents in the form of vortex rings to relatively great ranges. In particular, Prof. Tokmacher thought that the units adapted for use with machine guns could ultimately be rendered capable of disseminating extremely great quantities of toxic CW agents, at very rapid rates, with a very high degree of efficiency.

Prof. Tokmacher was present at the early military experiments. In these experiments ranges of 300 meters and ring (muzzle velocities of 70 meters/second were attained both with rifles and with machine guns. Vortex rings (1 meter overall diameter) were shot at a rate of 400/min. from a Degtyarer machine gun. "Tokmacher calculated that with 10 machine guns about one ton of war gas could be put out as vortex rings in four minutes."

Tokmacher was not invited to witness the tests conducted with the 76mm field gun, and thus we have no account of the results of the test. Though this test probably did not give the expected results, Tokmacher had calculated that a ring (muzzle) velocity of 1300 m./sec. could be obtained.

Due to the vagaries of Soviet politics the project was dropped after the tests with the 76mm gun, and from then on only occasional interest in the project was shown by the military authorities.

In 1942, Tokmacher was captured by the Germans, and he put his ideas and services at their disposal. The Germans performed various tests, the results of which largely confirmed Tokmacher's basic work. However, due to the demands of the war the Germans were not able to continue their work, and there is no record of their adapting vortex chambers for use in existing military weapons. It was from captured German accounts of these experiments, that our knowledge of Tokmacher, his history, and his work was derived. By the end of the war Tokmacher had disappeared.

V. THEORETICAL

The mathematical theory of vortex rings has been rather fully treated in the classical works on hydrodynamics and aerodynamics. However only a limited body of experimental work is recorded in the literature. In particular there is very little data as to how the geometric parameters of the vortex forming chamber affect the properties of the rings. Nor is there very much information correlating the muzzle velocity of the blast used to form the rings, with the properties of the rings.

The vortex forming chamber can be regarded as serving two functions. One, is as a reservoir for the CW agent to be incorporated in a single vortex ring. To meet this requirement at least a certain volume will be needed. The second function is to form or modify the flow pattern of the blast so as to yield that flow pattern which will give optimum properties to the vortex rings (i.e. maximize the capacity, contents, velocity and range of the ring). A large size is not inherently needed for this function, and perhaps the introduction of the proper baffles or flow forming shapes may permit a reduction in the overly bulky size of the chamber.

A second problem on which very little information exists is, whether the vortex ring has the ability to carry internally an aerosol without centrifugally expelling the particulates making up the aerosol. This problem, which does not exist for gases, is of importance because of the many CW agents of low volatility which are most efficiently disseminated in the form of an aerosol.

VI. DEVELOPMENT PROGRAM

A. The first tests will be conducted on systems patterned, as closely as possible, after those presented in the basic report on Tokmacher's work.

1. The following items will be used as propellant gas sources:

a. 30 caliber rifle
b. 30 caliber machine gun
c. 20mm cannon
d. Special explosive chambers

2. These items will be used in conjunction with a) standard blank cartridges, b) standard cartridges, c) specially modified cartridges and d) loose and formed explosive charges. Charges of black powder up to 70 grams in weight will be used.

3. Vortex forming chambers of the following sizes and shapes will be used in conjunction with the aforementioned weapons and munitions:

a. Pear shaped chambers
length 80 inches (approx.)
tip end diameter 2 inches
maximum diameter 40 inches
orifice diameters 15 inches, 24 inches, 30 inches

b. Ovoid chambers: to be adapted from jettisonable fuel tanks.

c. Conical chambers
length 80 inches
tip end diameter 2 inches
base diameter 40 inches
orifice diameter 15 inches, 21 inches, 24 inches, 30 inches

d. Small pear shaped chambers
length 10 inches
maximum diameter 8 inches
orifice diameter 3, 4, 6 inches
tip diameter 3/4 inch

e. Small cone shaped chambers
length 12 inches
base diameter 8 inches
tip diameter 3/4 inch
orifice diameters 3, 4, 6 inches

f. Other shapes and sizes as experience, convenience, and logical inference may dictate

B. Various other propellant systems will be tested in conjunction with the aforementioned vortex forming chambers. Such systems as the following may be used:

1. Pulse jet engines
2. Modified shaped charges

C. The aforementioned tests will be run using varying powder or propellant charges to observe their effect on the existence, range, velocity, and size of the resultant vortex rings.

D. Tests will be run using heavier than air gases, CO_2, illuminating gas, Pyrofax), lighter than air gases, (Hydrogen, CO, Nitrogen) vapors (NH_3, $SiCl_4$), and aerosols to determine what proportion of each of the various types of systems is conserved within the vortex over its entire range of travel.

E. Tests will be run to determine whether the destructive interference can be used as a range determinant for laying down smoke screens or toxic cloudr at specified distances from the generators. To accomplish this two systems can be used; 1. One system could consist of two generators aimed to give converging ring trajectories and capable of being fired simultaneously. The range would be determined by the point of convergence which in turn could be determined by the angle between the trajectories and the separation distance between the generators. With two generators mounted a fixed distance apart the sole determinant for the range would be the angle between the trajectories. 2. The second system will utilize the destructive interference set up between two coaxially projected rings. It has been noted, that when vortex rings are emitted in rapid succession, the distance between successive rings becomes less and less as the rings travel farther out from their source. When the distance between successive rings becomes less than one ring diameter, destructive interference is set up and the ring contents are in effect "dumped" at this point of ring breakup. The original spacing between rings is determined by the frequency of emission and the emission velocity. Using a unit having a constant emission velocity, the breakup distance becomes solely a function of the frequency of emission. Thus it should be possible to lay down a smoke screen, or a toxic cloud at varying predetermined distances from

the source generator by varying the frequency of emission of that source generator.

Unfortunately no available military weapon has an automatically variable and controllable rate of fire. To test this system of range determination, a chamber will be used in conjunction with a pulse jet engine. Different check values, having different elastic constants will be used to vary the frequency of pulsing of the jet.

VII. PROPOSAL

Should the aforementioned test program demonstrate that it is feasible to project, or disseminate CW agents by means of vortex ring producing devices, a research program should be started to determine the fundamental physical properties of vortex rings. The manner in which those parameters embodied in the geometry of the forming chamber, and the physical nature of the forming blast should determine these physical properties.

Such a research program should have the following ultimate goals; finding methods of maximizing and/or controlling the velocity, range, capacity and shearing power of vortex rings; and determining whether a reduction in the volume of the vortex forming chamber can be affected.

/s/ Henry Schwartzberg
HENRY SCHWARTZBERG
Applied Research Branch

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REPORT OF TEST

MEMORANDUM TO: Chief, Test Division

Project or Job No. 4-04-15-007
Date of Test 25 March 1952
Location
Division Munitions
Date of Report 28 March 1952

1. Item Tested:

Two small vortex chambers 12-in. long, 6-in. maximum diameter, 3-3/4-in. orifice diameter, 3/4-in. barrel diameter, (pear shaped) one containing and interior baffle.

2. Purpose:

a. To determine whether said chambers are capable of producing vortex rings upon being explosively pulsed by the blast emanating from a blank cartridge fired from a 30 cal. rifle.

b. To compare the effectiveness of said chambers for producing vortex rings.

c. To observe the properties and behaviour of the rings produced.

3. Method of Test:

The chambers were fastened to the end of a 30. cal. rifle by a clamp on their barrel diameters. Swabs containing NH_3 and HCl were inserted in the chambers producing smoke. Blank cartridges were fired from the rifle and the resultant vortex rings observed. The rifle was aimed at light shrubbery to observe the maximum distance at which vortex impact could be detected.

4. Conclusions:

Rings one to one and one-half feet in diameter were produced. They traveled at an estimated 20 to 30 ft. per second. Their effect could be felt 30 ft. from the orifice chamber. The rings themselves could be seen 20 ft. from the orifice. There was no significant difference in the behaviour of either chamber.

7. Results:

Twenty shots were fired, seven with the unbaffled chamber, 12 with the baffled chamber, and one with no chamber. In all instances when a chamber was mounted on the rifle, vortex rings were produced. They appeared to be between one and one and one-half feet in diameter and traveled at approximately 20 to 30 ft./sec. The rings were visible 20 ft. from the chamber and their effect in agitating light shrubbery was

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noticeable at ranges of 30 feet. When there was no chamber mounted, no rings were produced, nor was there any effect as to agitating shrubbery at a short range. There appeared to be no significant difference in the rings produced by either type of chamber.

8. Further Action to be Taken:

Modified small chambers will be fabricated and tested. The larger chamber will be tested after modification to mount a 20mm cannon. A more sensitive target structure will be built to determine the range of the RMCS.

SCHWARTZBERG/6122/mj W. A. SHOW C. B. DRENNON, Jr., Col, CmlC

Project Engineer Chief, App. Res. Branch Chief, Munitions Division

1 - Test Div.
1 - CEL
1 - Mun.
1 - App. Res. Br.
1 - Schwartzberg, App. Res. Br.

REPORT OF TEST

MEMORANDUM TO: Chief, Test Division

Project or Job No. 4-04-15-007
Date of Test 9 May 1952
Location Eglin Field
Division Munitions
Date of Report 28 May 1952

1. Item Tested:

Small vortex chamber - 30 cal rifle assembly.

2. Purpose:

To determine range to which vortices can be projected.

3. Method of Test:

The chamber was fastened on to the muzzle end of the rifle. Twenty blank cartridges were fired. The rifle was aimed either at a light target structure or at light foliage.

4. Conclusions:

The vortex is extremely difficult to aim and erratic in its flight This is probably due to variations in the alignment of the axis of the loosely fastened vortex chamber and the axis of the gun barrel; and to variation in the blast emanating from the blank cartridges.

5. Not applicable

6. Not applicable

7. Results:

It was difficult to determine the maximum range at which vortex impact could be felt because the point of impact seldom came near the point at which the rifle was aimed. Errors of 10 ft. at a range of 20 yds could readily be observed. These errors did not reproduce themselves, but changed in sign and magnitude. The maximum range at which vortex impact was observed, was 20 yds.

SCHRAMMBERG W. A. SHOW C. B. DEZENDORF, Jr., Col, Cml C

Project Engineer Chief, App. Res. Branch Chief, Munitions Division

APPENDIX P

Sketches

Fig. 1, Vortex Ring

Fig. 2, Diaphragm Actuated Vortex Chamber

Fig. 3, Small Vortex Chamber

Fig. 4, Small Vortex Chamber with Baffle

Fig. 5, Large Vortex Chamber

Fig. 6, Typical Vortex Chamber for the Production of the Vortex Ring

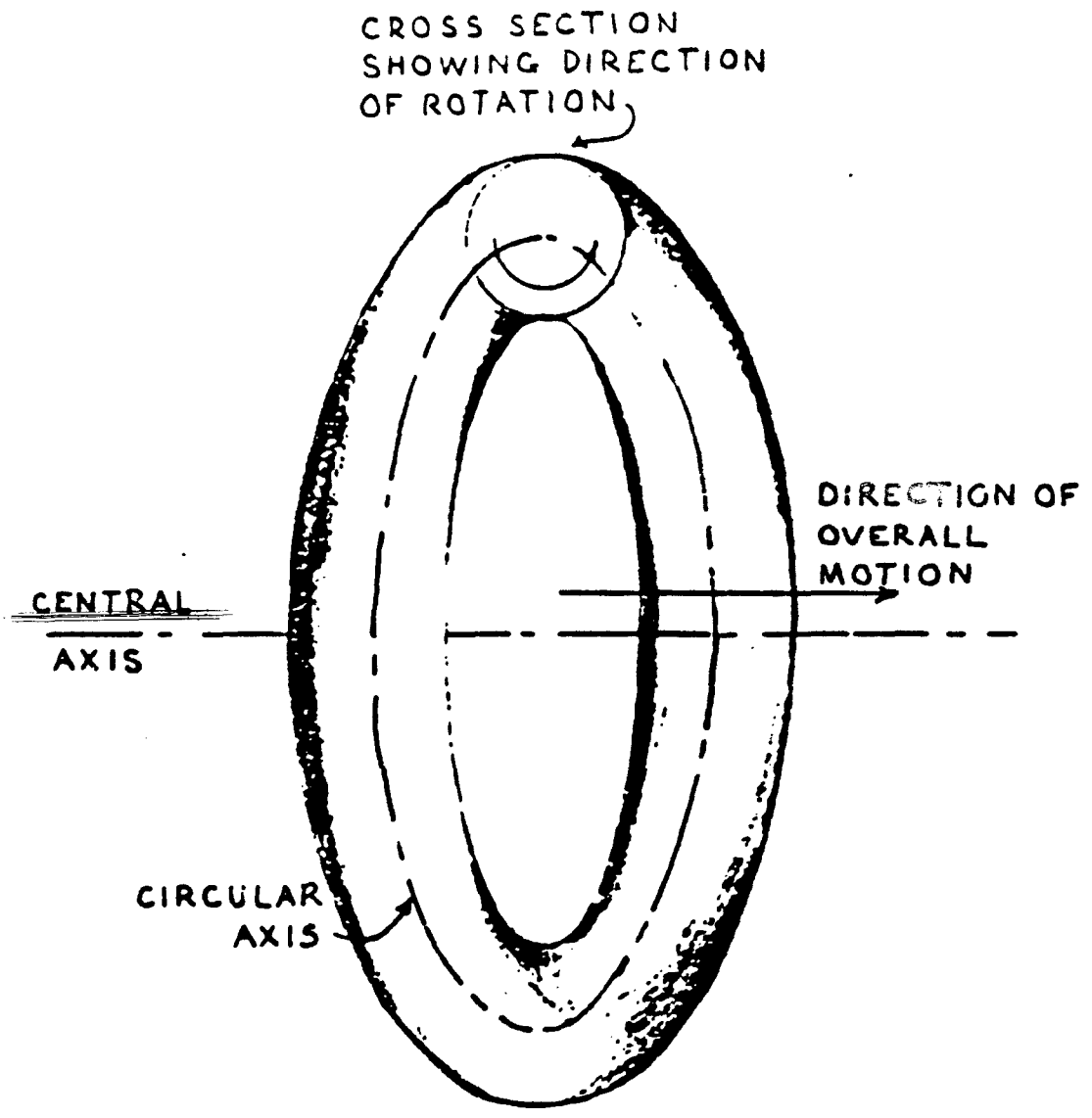

FIGURE 1
VORTEX RING

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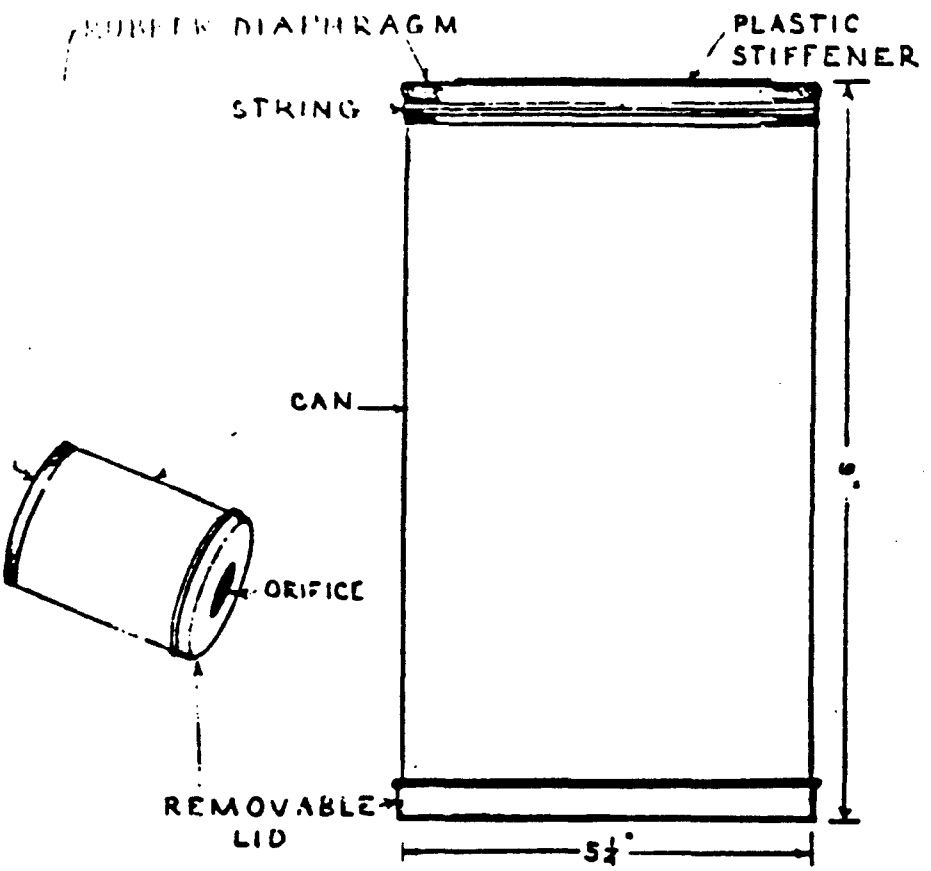

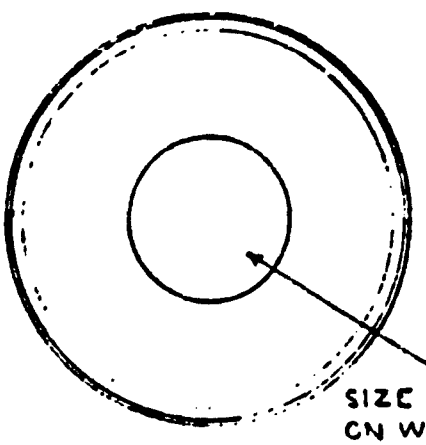

DIAPHRAGM ACTUATED VORTEX CHAMBER

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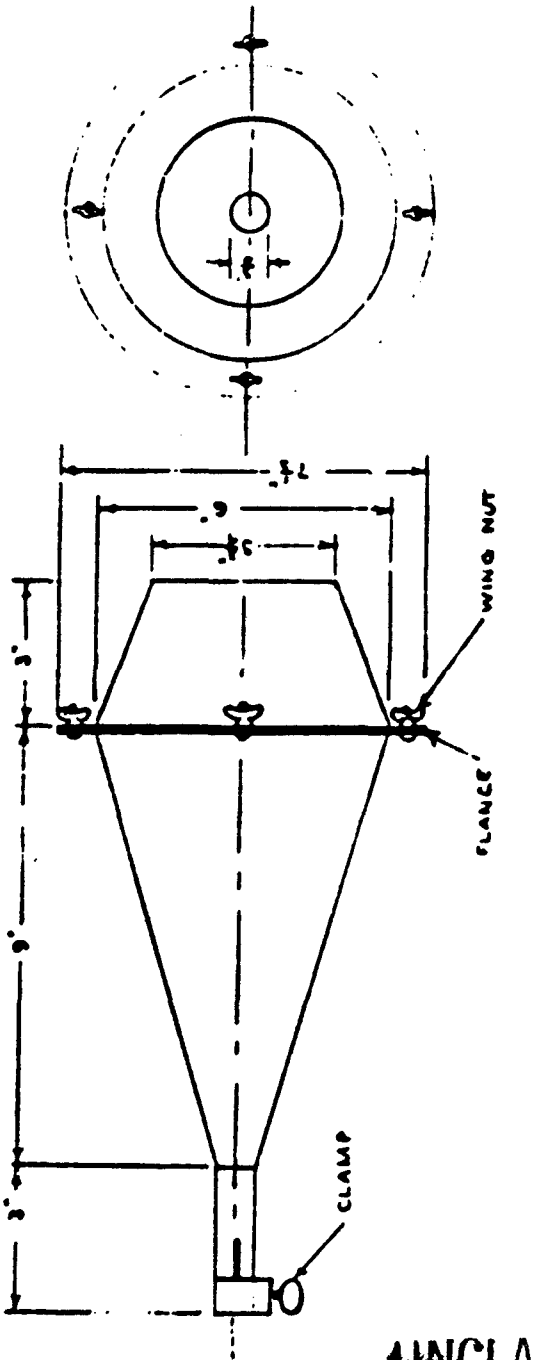

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SMALL VORTEX CHAMBER

FIGURE 3

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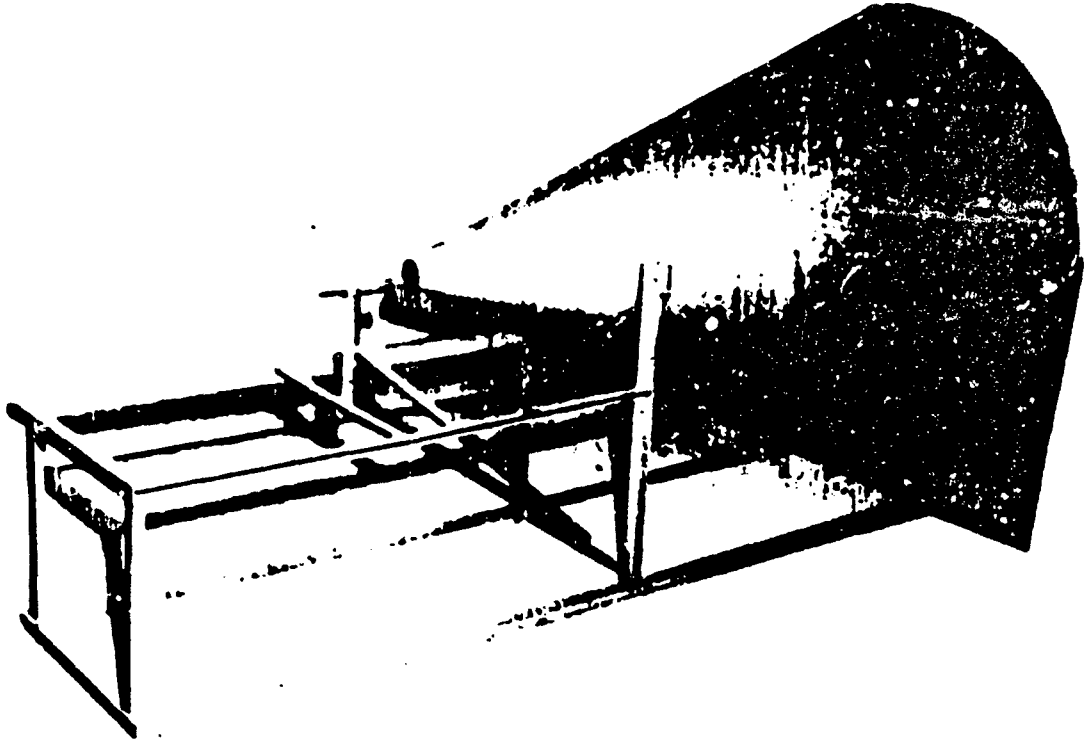

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FIGURE 6

TYPICAL VORTEX CHAMBER FOR THE PRODUCTION OF THE VORTEX RING

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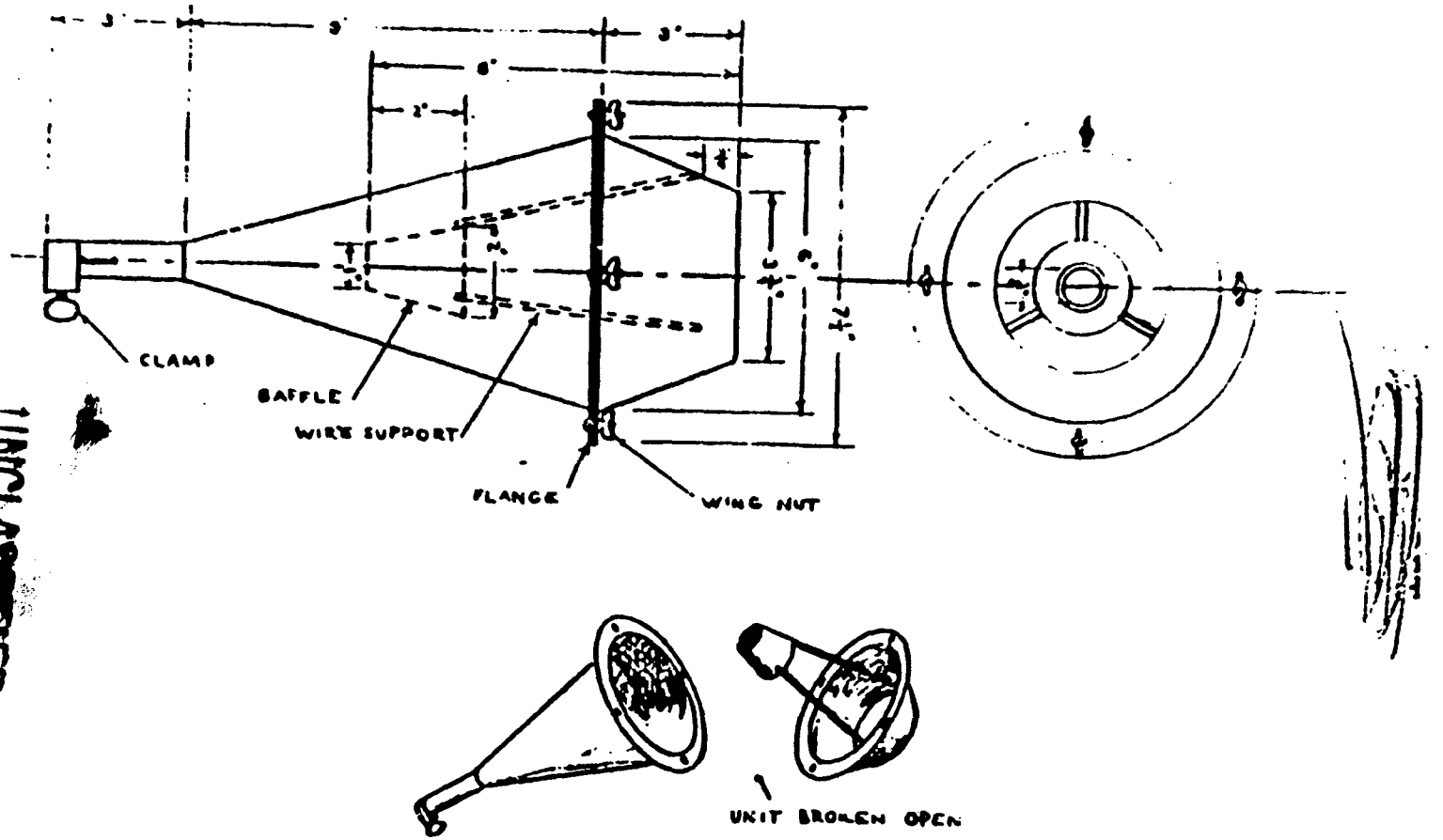

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SMALL VORTEX CHAMBER
WITH BAFFLE

FIGURE 4

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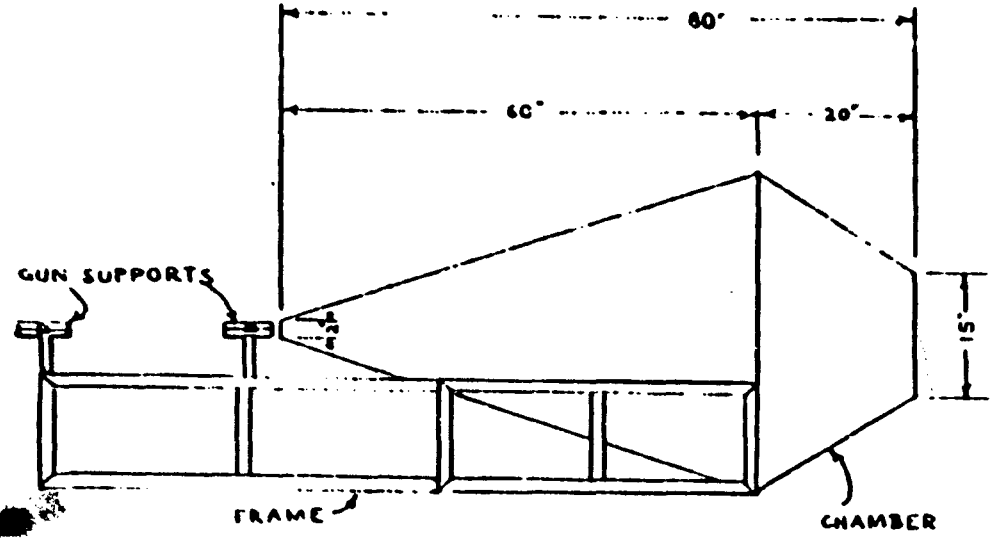

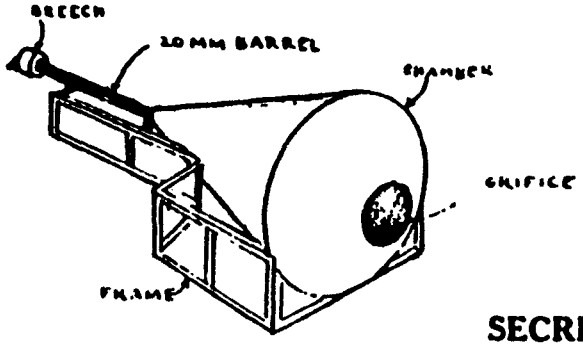

FIGURE 5
LARGE VORTEX CHAMBER

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