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SETBACK-SPIN SIMULATOR FOR 5-INCH AIR GUN
(Final Design Task Report)

NOL

27 DECEMBER 1968

UNITED STATES NAVAL ORDNANCE LABORATORY, WHITE OAK, MARYLAND 20910

NOLTR 68-219

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SETBACK-SPIN SIMULATOR
FOR 5-INCH AIR GUN
(Final Design Task Report)

Prepared by:

V. F. DeVost
Environment Simulation Division

ABSTRACT: Described is a removable adaptor that is used in the NOL 5-inch Air Gun to produce spin acceleration simultaneously with setback acceleration. The adaptor consists of a rifled breech block and a test vehicle with a 1-foot long spin accelerator (spiraled drive shaft). With the adaptor, the 5-inch gun can impart a peak setback acceleration of 20,000g, a peak spin acceleration of 240,000 rad/sec^2, and a spin velocity of 50 rps to a 5-pound payload.

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NOLTR 68-219 27 December 1968

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The Setback-Spin Simulator is the second of three facilities authorized for development under Office of Naval Material Task MAT 03L 204/F099 02 01 Problem 010. Work on the first, designated as the "VHg Impact Test Set", was completed and is reported in NOLTR 68-158. Work on the third, the "Setback-Spin Test Set", was terminated on completion of the feasibility study; the need anticipated for testing fuse components in production did not materialize, and it was later determined that gun-shock simulation at low velocity is inadequate for most design testing. Noteworthy results of the feasibility study are included in Appendix A. The Setback-Spin Simulator extends significantly the capability of the NOL 5-inch Air Gun and the state-of-the-art in the simulation of artillery projectile shock. This report completes work on this task.

The author acknowledges the contributions of Mr. J. W. Simkins of the Product Engineering Department who was responsible for most of the simulator design effort.

E. F. SCHREITER
Captain, USN
Commander

V. M. Korty

V. M. KORTY
By direction

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ILLUSTRATIONS

REFERENCES

(a) NOLR 1056, 2nd Rev, Shock Testing Facilities, Mar 1956
(b) NOLTR 67-194, Piezoelectric Accelerometer Signal Error in Complex Shock Recordings, Dec 1967
(c) NOLTR 68-85, WOX-5A Accelerometer, May 1968
(d) NOLTR 67-151, Shock Spectra Measurements Using Multiple Mechanical Gages, Sep 1967
(e) NOLTR 67-3, Artillery Projectile Shock, Jan 1967
(f) NOLTR 67-185, Test Set, Drop Shock, WOX-126C, Jan 1967

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INTRODUCTION

1. There has long been a need to simulate in the laboratory the combined effects of setback and spin accelerations produced in artillery projectiles. In the past these environments have been investigated separately. The setback environment has been simulated using air guns (ref. (a)). For the most part, efforts in simulating the spin environment have been restricted to using accurately controlled, motor-driven, high velocity spinners for purposes of studying the performance of spin-actuated devices. Limited spin-acceleration investigations have been conducted using jury-rigged apparatus; however, no permanent facility exists for producing the spin accelerations encountered in surface gun firings. The setback-spin simulator* combines in one test the effects of setback and spin accelerations.

2. The NOL 5-inch air gun is used to simulate other effects of high-g shock not necessarily associated with artillery projectiles. For this reason the setback-spin simulator was designed to be used interchangeably with existing gun equipment; no change had to be made in the existing 5-inch air gun design.

3. Before reaching the decision to design the subject simulator, feasibility studies on two explosive type setback-spin simulators were conducted at the Naval Weapons Laboratory, Dahlgren, Virginia. Noteworthy results of the studies are summarized in Appendix A. Also presented in Appendix A is a brief summary of a study conducted on the design of a setback-spin test set.

DESCRIPTION

GENERAL

4. The simulator as adapted to the 5-inch gun, figure 1, has the capability of attaining a 20,000g setback acceleration, a 240,000-rad/sec² angular acceleration, and a 50-rps spin velocity. Its payload capacity for the above parameters is 5 pounds. The test vehicle tare weight, including the spin accelerator, is 10 pounds.

5. As shown in figure 2, the adaptor consists of two assemblies: a chamber block (also referred to as breech block) and a test vehicle equipped with a spin accelerator (spiraled drive shaft). The breech block provides the chamber for the accelerating air charge as well as the release valve for firing the test vehicle. It also contains the

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*Throughout this report "adaptor" and "simulator" are used interchangeably.

rifling in which the spin accelerator shaft travels. The test vehicle holds the test item (fuze or fuze component). The spin accelerator shaft is rigidly attached to the back of the test vehicle and travels with it during firing. Details of the simulator components are described in the following paragraphs and are numerically keyed to figure 2.

SIMULATOR COMPONENTS

6. CHAMBER BLOCK (ITEM 1). When assembled in the 5-inch air gun the chamber block, made of 75ST6 aluminum, forms an air chamber of 0.106 cubic foot volume. The block also contains air ports and a recessed seat that is part of the air valve for firing the test vehicle — the other part of the air valve is the test vehicle base.

7. RIFLING RING (ITEM 2). Firmly attached inside the chamber block is a rifled steel ring. Rifling is uniform at 7.5 degrees per inch ($\pi/2$ radians per foot). Essentially, the rifling consists of four keys equally spaced inside the steel ring. The ring and the chamber block remain fixed during firing.

8. SPIN ACCELERATOR (ITEM 3). The spin accelerator is a 2-inch diameter by 1-foot long hollow shaft fabricated from 75ST6 aluminum. The shaft contains spiraled grooves that match closely the rifling keys in the chamber block ring (see Item 2). The shaft threads into the back of the test vehicle and remains fixed to the vehicle.

9. TEST VEHICLE (ITEM 4). Except for the spin accelerator (Item 3), the test vehicle used in the simulator is the same as that used in conventional tests run in the 5-inch air gun when the air valve release is used — the gun also has a diaphragm release mechanism which is used interchangeably with the air valve system. The vehicle is bored out 2-1/8 inches in diameter by 7-5/8 inches deep to receive fuze assemblies or fuze components. The leading portion of the bore has a 2-3/8 - 12 R.H. thread.

OPERATION PRINCIPLE

AIR VALVE FIRING

10. The 5-inch air gun is operated with two types of release systems. The one most often used, because of its high peak-shock efficiency, is the shear-diaphragm release — the release is described in reference (a). A second system, an air valve release, is used when more precise command firing is desired or when a longer shock pulse rise time is required. The air valve release system produces a peak acceleration that is approximately 62 percent of that obtained with a shear-diaphragm release system under otherwise identical firing conditions. The air valve system was selected for use with the simulator because the rise time of the shock pulse produced is much closer to the rise time of surface gun shocks than is the rise time of the diaphragm system shock. The pulse rise time of the diaphragm release is approximately 100 μs; that of the air valve release is approximately 1 ms.

11. The simulator release operates on a quick-opening valve principle. As shown in figure 2, the base of the test vehicle and the seat or recess in the chamber block containing the air ports make up the air valve mechanism. The air charge used to accelerate the test vehicle is stored in an annular chamber around the chamber block and exerts a static force around the test vehicle through the air ports. The force is balanced since O-ring seals prevent pressure from acting behind or ahead of the vehicle.

12. To fire the test vehicle, high pressure air is suddenly released behind the vehicle through a separate valve (see blow-off air chamber, figure 2). The pressure drives the test vehicle forward until the back O-ring seal uncovers the air ports, allowing the air charge around the vehicle to escape. The pressure then acts against the back of the vehicle and accelerates it down the barrel.

TEST VEHICLE MOTION

13. Linear and angular accelerations of the test vehicle occur simultaneously as the vehicle is fired and are proportional for the first foot of travel. Since the spin accelerator grooves are uniformly spiraled at one-quarter turn ($\pi/2$ radians) per foot, the relationship between angular (α) and linear acceleration (A) is

$$\alpha = A_{average} \times g \times \frac{\pi}{2} \times \frac{1}{1\ ft}$$

$$= 16.1\ \pi\ A_{average} \quad rad/sec^2$$

CALIBRATION

SETBACK (LINEAR) ACCELERATION

14. Calibration of the 5-inch air gun using continuous reading accelerometers poses many problems. Closed gun firings do not easily lend themselves to current state-of-the-art, hard-wire instrumentation which is the best technique for obtaining acceleration-time data. Using this type of instrumentation the test vehicle must be fired toward the transducer cable. This is at best a hit-and-miss operation. However, by using mechanical gages as backup instrumentation and by making judicious use of the known parameters of shock (firing pressure, energy, computed vehicle velocity, etc.) it has been possible to calibrate the 5-inch air gun for setback acceleration with acceptable accuracy (less than ±5 percent error).

ANGULAR (SPIN) ACCELERATION

15. Measurement of angular acceleration using commercial shock transducers and hard-wire instrumentation was not attempted. To record angular acceleration it is necessary to mount the shock transducer tangentially on the test vehicle and transverse to setback shock. Commercial transducers cannot record with any acceptable

accuracy* any shock containing high amplitude and high frequency transverse components such as that contained in the 5-inch air gun setback shock. Angular acceleration was computed using linear acceleration data and was measured with the WOX-5A Angular Copper-Ball Accelerometer, reference (c).

CALIBRATION RESULTS

16. Continuous recording had been run originally on a 9.75-pound test vehicle using the air valve release system but containing no spin accelerator. Oscillograms of the shocks recorded are shown in figure 3. The same shocks were also measured with a 2180-Hz, Mod 3 Copper-Ball Accelerometer**— a relatively low frequency accelerometer was selected in order to measure the peak of the fundamental pulse (air gun shocks contain high frequency components). The peaks measured continuously were 67 percent of theoretical; those measured with the copper-ball accelerometer were 85 percent of theoretical or 25 percent higher. The data are compared in figure 4.

17. The mechanical gage measurements described in paragraph 16 were repeated on an 11-pound setback-spin simulator vehicle to determine whether spin acceleration and drag significantly reduced linear peak acceleration. The setback-spin vehicle measurements were within 4 percent of the nonspin vehicle on the high side, figure 5.

PERFORMANCE

18. To meet most artillery projectile requirements the original goals for the setback-spin simulator were 25,000g and 250,000 rad/sec^2 or higher. The prototype simulator falls slightly short of these goals. The acceleration levels, however, can be increased if the efficiency of the gun is increased. Alternately the levels can be increased by increasing the chamber volume. This will necessitate the lengthening of the present gun barrel. Also, the simulator can be easily adapted to diaphragm operation which will increase the efficiency. See paragraph 22 for alternate design proposals.

19. Because of spin accelerator space limitations (1 foot of travel), the angular acceleration duration of the test vehicle is relatively short — approximately one-quarter of the linear acceleration duration. This results in a spin velocity of 50 rps. Currently there are no requirements to test at higher spin velocity; however, if higher spin is required this may be accomplished by increasing the spiral angle of the spin accelerator.

20. The mechanism for combining linear and angular acceleration is relatively simple and provides a positive means of determining levels of angular acceleration if the linear acceleration is known.

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*Signal error in commercial transducers is discussed in reference (b).

**See reference (d) for description of accelerometers.

CONCLUDING COMMENTS

21. The success achieved with the prototype simulator has shown that rifling can be used compatibly in smooth bore air guns to simulate the effects of artillery projectile shocks. But there still remain some problems to be solved in air guns to improve simulation. The shocks produced should be longer in duration and the spin velocity should be higher. Such effects as torsional chatter and barrel slap should be simulated along with setback and spin acceleration.

22. Future effort should be directed toward achieving the above goals. The problem is not considered a difficult one; essentially it means increasing firing pressure by about 25 percent and doubling chamber volume. The present 5-inch air gun has only about 50 feet of barrel; extending its length to 200 feet would greatly increase its efficiency. With the longer barrel, in-bore rifling could be used and extended to 4 feet; this would increase considerably the spin velocity and acceleration capability of the gun. One scheme for producing torsional chatter and barrel slap is to increase the clearance between the spin accelerator and rifling ring and between the gun bore and test vehicle.

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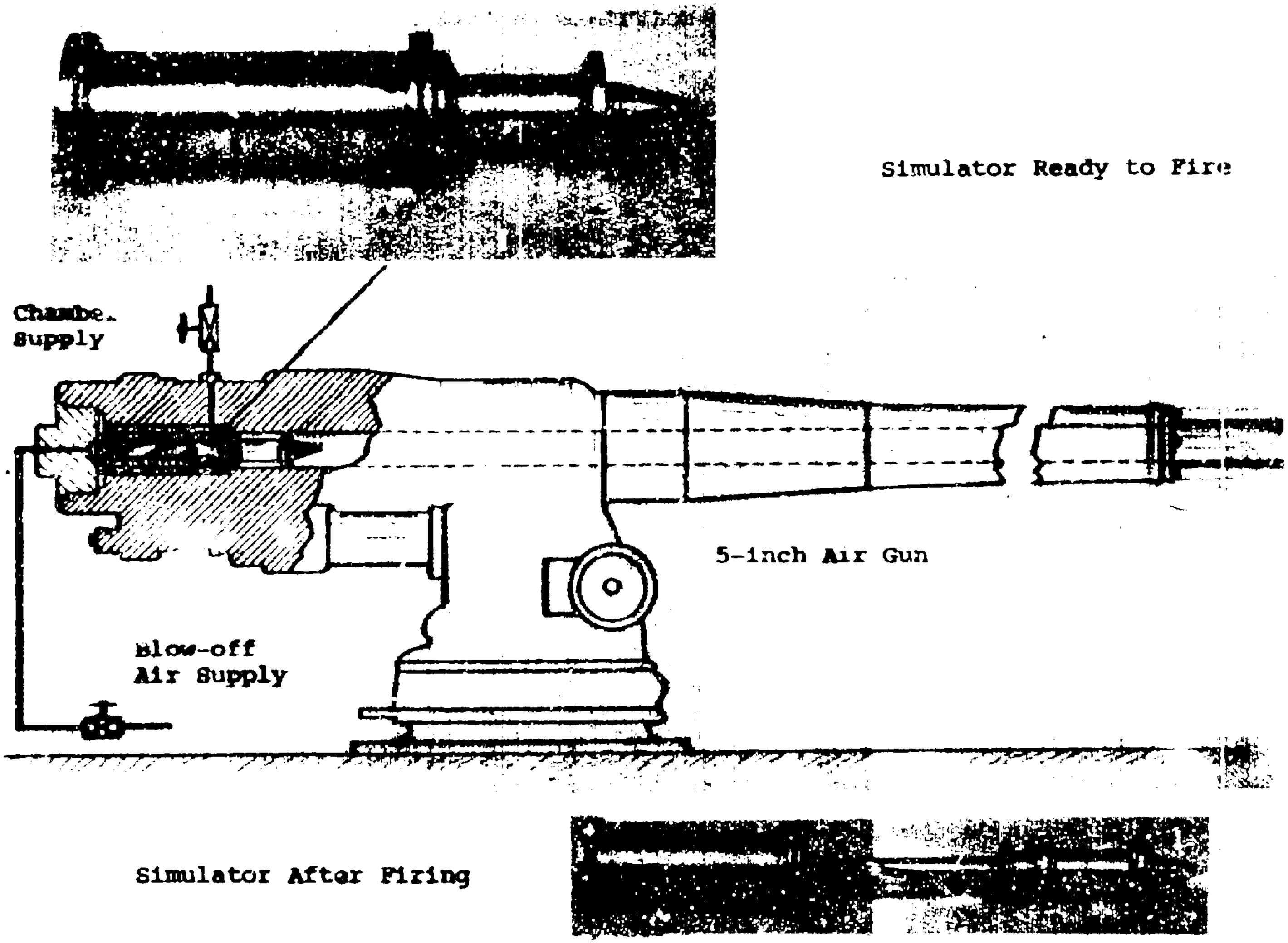


FIG. 1 SETBACK SPIN SIMULATOR AND 5-INCH AIR GUN

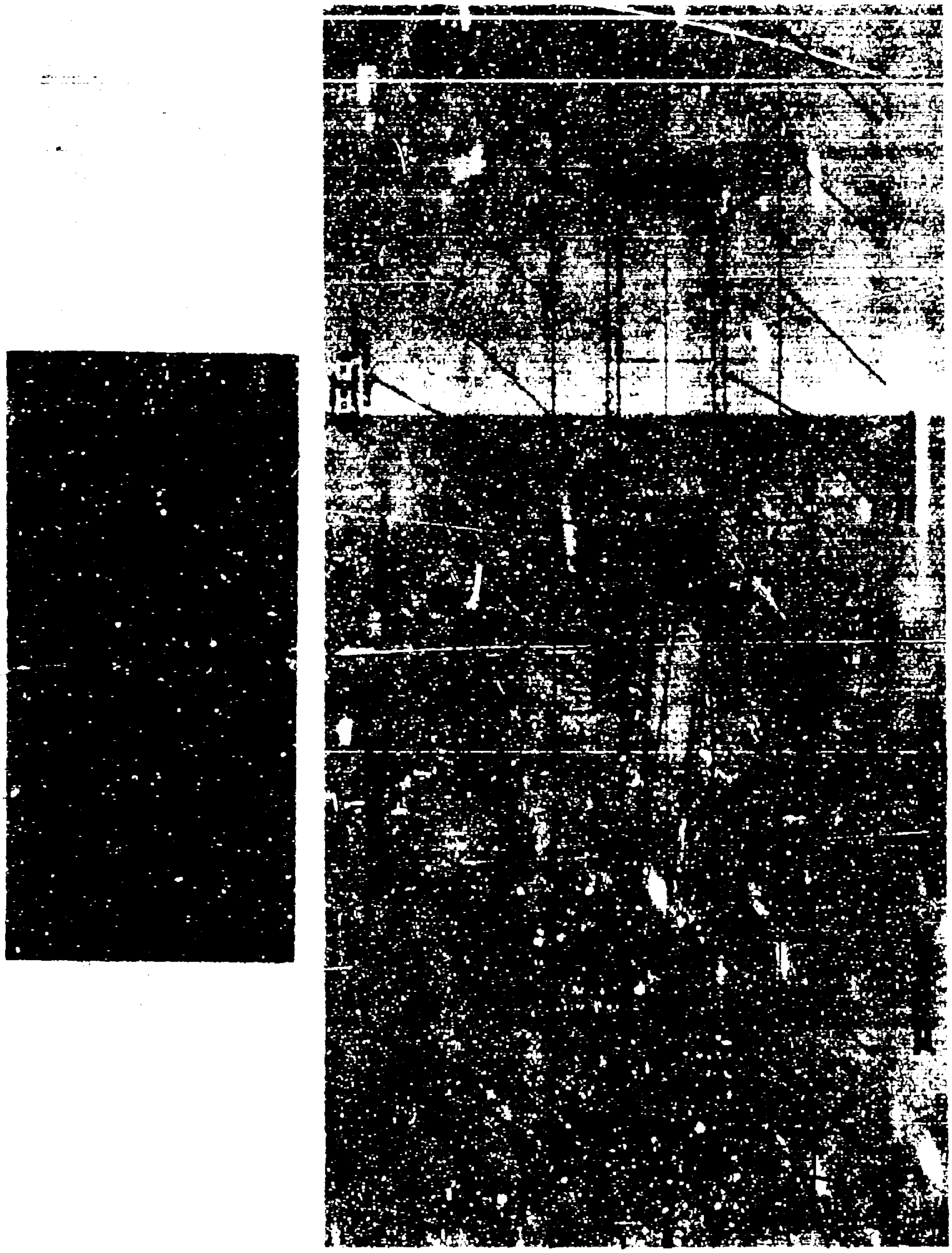
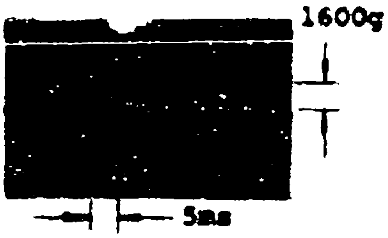
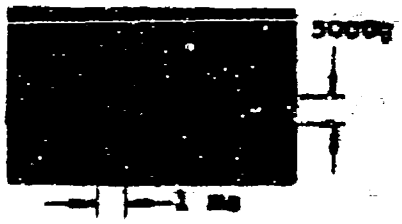


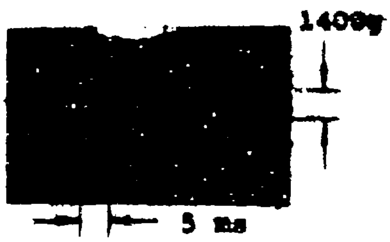
FIG. 2 SIMULATOR COMPONENTS



1000-psi Shot

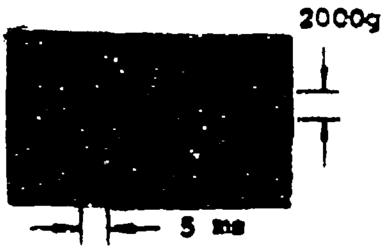


6000-psi Shot

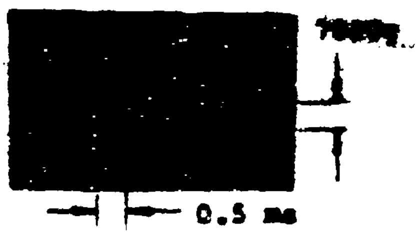


2000-psi Shot

9000-psi Shot



3000-psi Shot



10,000-psi Shot

FIG. 3 CALIBRATION OSCILLOGRAMS

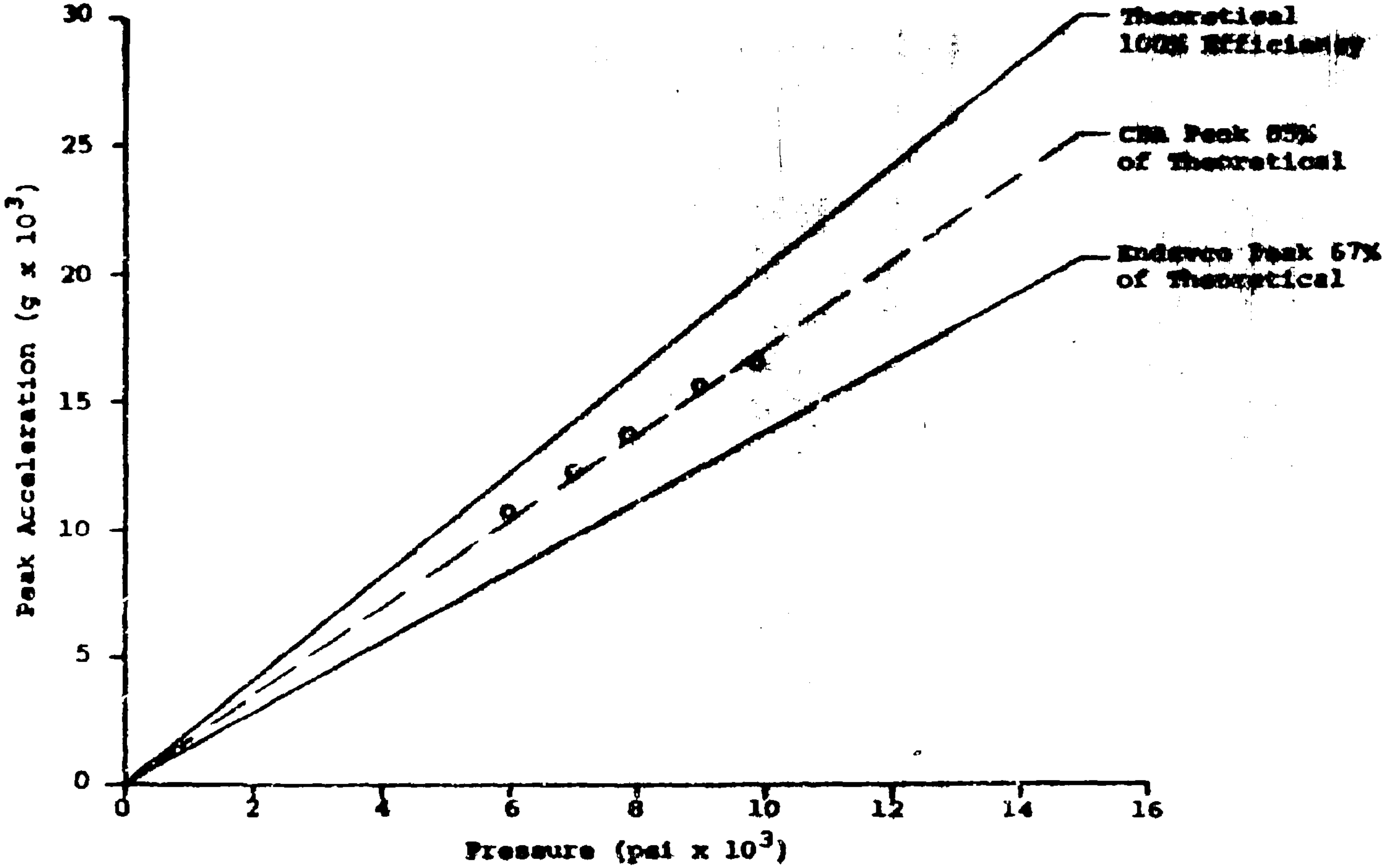


FIG. 4 NONSPIN VEHICLE (9.75 POUNDS) LINEAR ACCELERATION

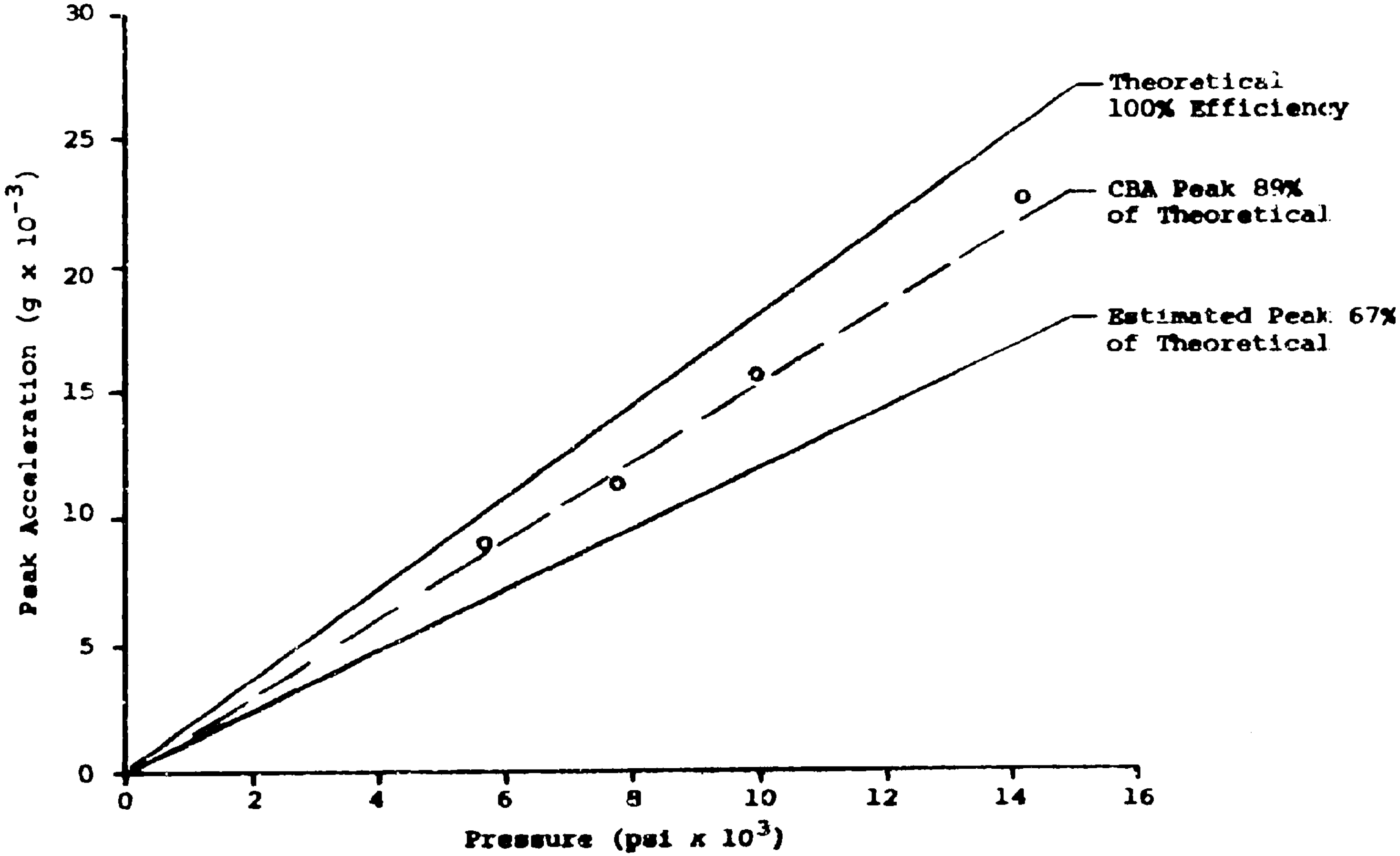


FIG. 5 SETBACK-SPIN SIMULATOR VEHICLE (11 POUNDS) LINEAR ACCELERATION

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Appendix A

SUMMARY OF FEASIBILITY STUDIES

A-1. Feasibility studies were conducted as part of the design effort for both the Setback-Spin Simulator and the Setback-Spin Test Set. Studies on the simulator were conducted at the Naval Weapons Laboratory, Dahlgren, using a 3"/50 gun; studies on the test set were conducted at NOL using a sub-scale model.

GUN STUDIES

A-2. The initial proposal for a setback-spin simulator suggested the use of explosives to accelerate the test vehicle (projectile). Feasibility tests were run on a 3"/50 gun system using standard pilot ejection cartridges in a special adaptor and using reduced charges in standard cartridges to accelerate the test vehicle (modified 3"/50 projectiles).

A-3. For the first series of tests a Mk 3 Mod 1 pilot ejection cartridge was adapted to a 3"/50 cartridge and a test vehicle was made up from a standard 3"/50 projectile. The inert charge was removed from the projectile and the engraving band was pregrooved to match the rifling. The cartridge case and test vehicle had the same fixed ammunition configurations as standard 3"/50 rounds. The assembly is shown in figure A-1. The cartridge selected for the test had a rated energy output of 64,000 ft-lb and a rated nominal peak pressure output of 20,000 psi.

A-4. Three shots were fired using the cartridges. Results of the tests were negative. Gas blowby in the gun was excessive for the limited energy of the cartridge. The highest vehicle velocity achieved was 220 fps or about 20 percent of the minimum design objective for an adequate setback-spin simulator. Also, the setback shock measured was an order of magnitude lower than that measured in 5"/54 and 5"/38 guns, reference (e).

A-5. In the second series of tests standard 3"/50 ammunition with inert projectiles and reduced charges was used. By limiting vehicle velocity to about 1000 fps it was estimated that gun blast could be reduced sufficiently to permit gun firings in the open at NOL.

A-6. Five tests were run using charges ranging from 17 percent to 25 percent of full. Velocities ranged from 981 fps to 1273 fps — full charge velocity is approximately 2800 fps. In the opinion of

NWLD Main Range personnel, gun blast at 981 fps was no louder than that normally produced by a high powered rifle; however, at reduced charge the peak breech pressure at the lower velocities dropped to less than 20 percent of full charge. The reduced pressures were considered to be too low to achieve adequate peak acceleration for setback-spin simulation.

A-7. The principal disadvantage in using explosives to accelerate test vehicles, aside from safety and noise considerations, is gas blowby. There is no practical way to seal rifled guns for efficient operation at reduced charge. The only alternative would be to operate above 50 percent of full charge; however, the cost of providing a noise barrier for the gun and higher capacity recovery facilities would be prohibitive. As discussed in the body of the report, this scheme was abandoned in favor of one using compressed air.

TEST SET STUDIES

A-8. The Setback-Spin Test Set proposed for development suggested the use of colliding vehicles to provide maximum impact velocity change over a limited travel distance and to absorb impact loads between colliding masses instead of with massive foundations or seismic platforms. Success of the proposed method depended chiefly on the feasibility of releasing two test vehicles simultaneously. To study the performance of a mechanical release for the vehicles and other design features, a one-eighth scale, working model of a prototype test set was designed and constructed. Figure A-2 shows the basic test set design and lists its principal parts.

A-9. Briefly, the prototype design shown proposes the use of shock cord, part no. 9 (rubber bands in the model), to propel the test vehicles and a common drive shaft with opposing screw threads, part no. 15, to cock the system. The lead screw was driven by a small electric motor and a gear reducer, part no. 19.

A-10. The tester operates as follows.

a. Two release mechanisms, part no. 17, engage the test vehicles and are driven by a screw-threaded shaft, part no. 15, in opposite directions to the cocked position shown in figure A-2.

b. A common cam shaft, part no. 16, is turned suddenly to depress the release pawls, part no. 14; thus the shaft simultaneously releases both vehicles.

c. After the vehicles are released they accelerate toward each other until they collide. The first collision occurs between the lightweight fuze holder, part no. 5, and the impact vehicle. At impact the pin holding the fuze holder, part no. 4, shears and the holder is driven back and into the test vehicle. As the holder accelerates linearly inside the test vehicle, two keys, part no. 3, projecting into the helical grooves of the holder, spin the holder. After impact with the holder, the impact vehicle collides with the test vehicle and the fuze holder is stopped by a lead pad, part no. 1, as it strikes the base of the test vehicle — the pad is attached to the base of the fuze holder. This completes the test cycle.

A-11. In the proposed test set design maximum velocity change of the fuze holder was to be achieved by making optimum use of vehicle momentum. The proposed test set was to have vehicles of equal weight (gross) and a fuze holder of approximately one-tenth the weight of the impact vehicle. The fuze holder impact pad, part no. 7, was to have a high impact coefficient (coefficient of restitution) to provide maximum rebound velocity of the holder during impact. The principle of operation is as follows.

a. Both vehicles, accelerated by the same force, reach the same velocity at the instant of impact.

b. At impact the fuze holder is stopped momentarily by the impact vehicle; its velocity change at this instant is equal to its striking velocity.

c. Because the impact vehicle has a larger mass (10 to 1), its velocity changes little during impact with the holder; therefore, it adds its remaining velocity to the velocity change of the fuze holder.

d. Rebound of the holder after impact further increases its velocity change. The increase depends on the impact coefficient of the colliding components.

A-12. The operating principle can be described in quantitative terms by computing the motion of the colliding masses using the conservation of momentum method. Plans for the full scale test set called for vehicles of 50 pounds, with the test vehicle carrying a 5-pound fuze holder. Vehicle velocities were to be 50 fps. The material for the fuze holder impact pad was to be "Delrin", a high strength plastic with a high (0.8) coefficient of restitution — see reference (f). The equations of motion and computations for the fuze holder and impact vehicle for the above-mentioned design parameters are as follows:

$$w_1 v_1 + w_2 v_2 = w_1 v_1' + w_2 v_2' \qquad (1)$$

$$e(v_1 - v_2) = v_2' - v_1' \qquad (2)$$

where w_1 = 5 lb, w_2 = 50 lb, v_1 = 50 fps, v_2 = -50 fps, and e = 0.8. Substituting in (1) and (2) and solving the equations simultaneously:

$$5 \times 50 + 50(-50) = 5v_1' + 50v_2'$$

$$0.8[5 - (-50)] = -v_1' + v_2'$$

$$
\begin{array}{r}
-2250 = 5v_1' + 50v_2' \\
-2200 = 50v_1' - 50v_2' \\
\hline
-4450 = 55v_1'
\end{array}
$$

$$v_1' = -81 \text{ fps}$$

The fuze holder velocity change is equal to its striking velocity plus its velocity after impact or 131 fps. This is 160 percent of the velocity possible with a single vehicle assuming zero bounce.

A-13. The model tests were run to study the release action and motion of the vehicles with high speed photography. Releases were made with the cam shaft actuator, part no. 12, operated manually at speeds ranging from approximately one-half to one second. Even at the slowest actuation time, release of both vehicles resulted in impacts within one-eighth inch of dead center. Vehicle velocities were approximately 35 fps in all tests.

A-14. Results of the study clearly indicate that a mechanical release is feasible for achieving simultaneous release of high velocity vehicles. In the full scale test set the cam shaft actuator would normally be actuated by a fast-acting solenoid or pneumatic plunger and actuation time would be much faster and more positive. Assessment of the design and operation of the model test set showed generally that a full scale test set could be designed along the same lines as the model. The salient features of the design are as follows.

a. The machine frame, part no. 18, would require no massive emplacement since all reaction forces are taken up by the vehicles (are balanced).

b. The vehicles are safely contained in a closed tube, part no. 11.

c. A large access door, part no. 8, makes loading and unloading of the test item easy. Also, the access door and short travel of the vehicles makes instrumentation of the tester much simpler.

d. The design is compact enough for a portable test set.

e. The design is not restricted to setback-spin test set applications only; it can be adapted for producing other high velocity impact shocks.

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$$w_1 v_1 + w_2 v_2 = w_1 v_1' + w_2 v_2' \qquad (1)$$

$$e(v_1 - v_2) = v_2' - v_1' \qquad (2)$$

where $w_1 = 5$ lb, $w_2 = 50$ lb, $v_1 = 50$ fps, $v_2 = -50$ fps, and $e = 0.8$. Substituting in (1) and (2) and solving the equations simultaneously:

$$5 \times 50 + 50(-50) = 5v_1' + 50v_2'$$

$$0.8[5 - (-50)] = -v_1' + v_2'$$

$$-2250 = 5v_1' + 50v_2'$$

$$-2200 = 50v_1' - 50v_2'$$

$$-4450 = 55v_1'$$

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a. The machine frame, part no. 18, would require no massive emplacement since all reaction forces are taken up by the vehicles (are balanced).

b. The vehicles are safely contained in a closed tube, part no. 11.

c. A large access door, part no. 8, makes loading and unloading of the test item easy. Also, the access door and short travel of the vehicles makes instrumentation of the tester much simpler.

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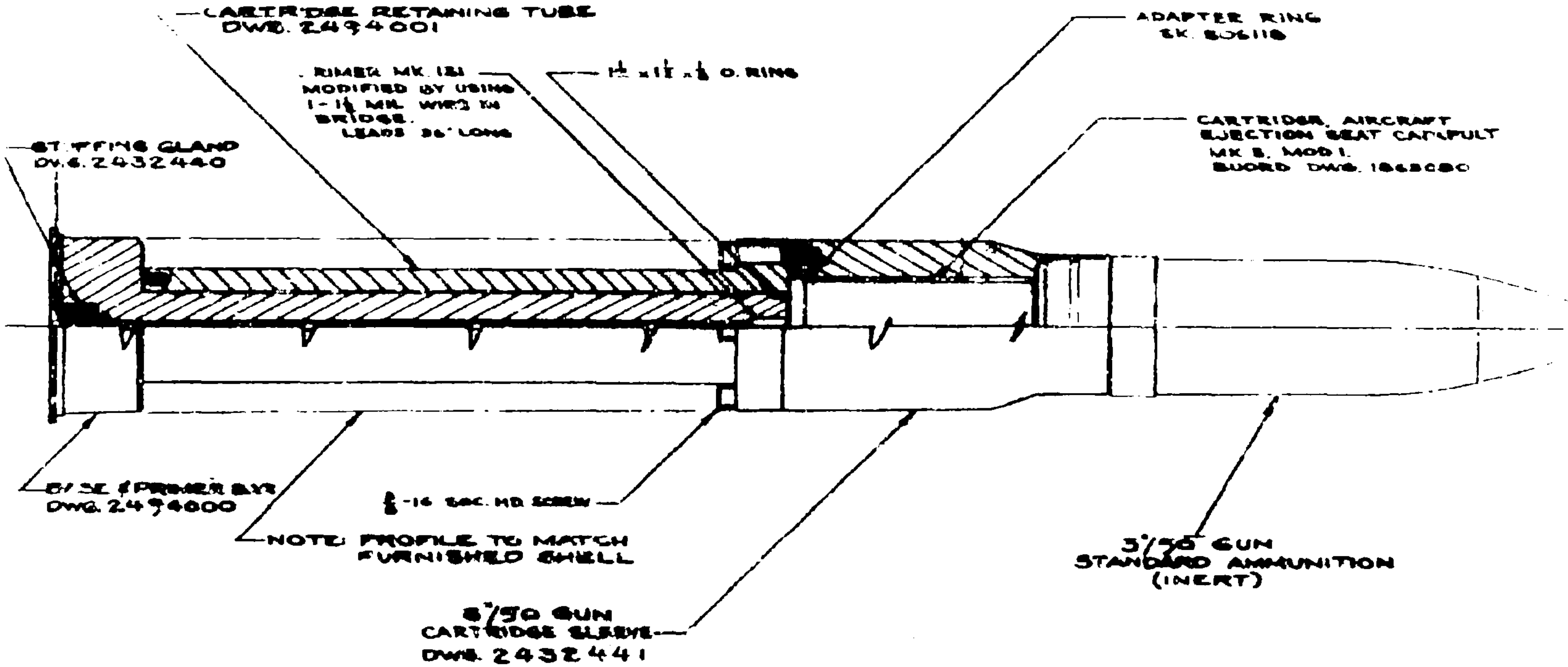
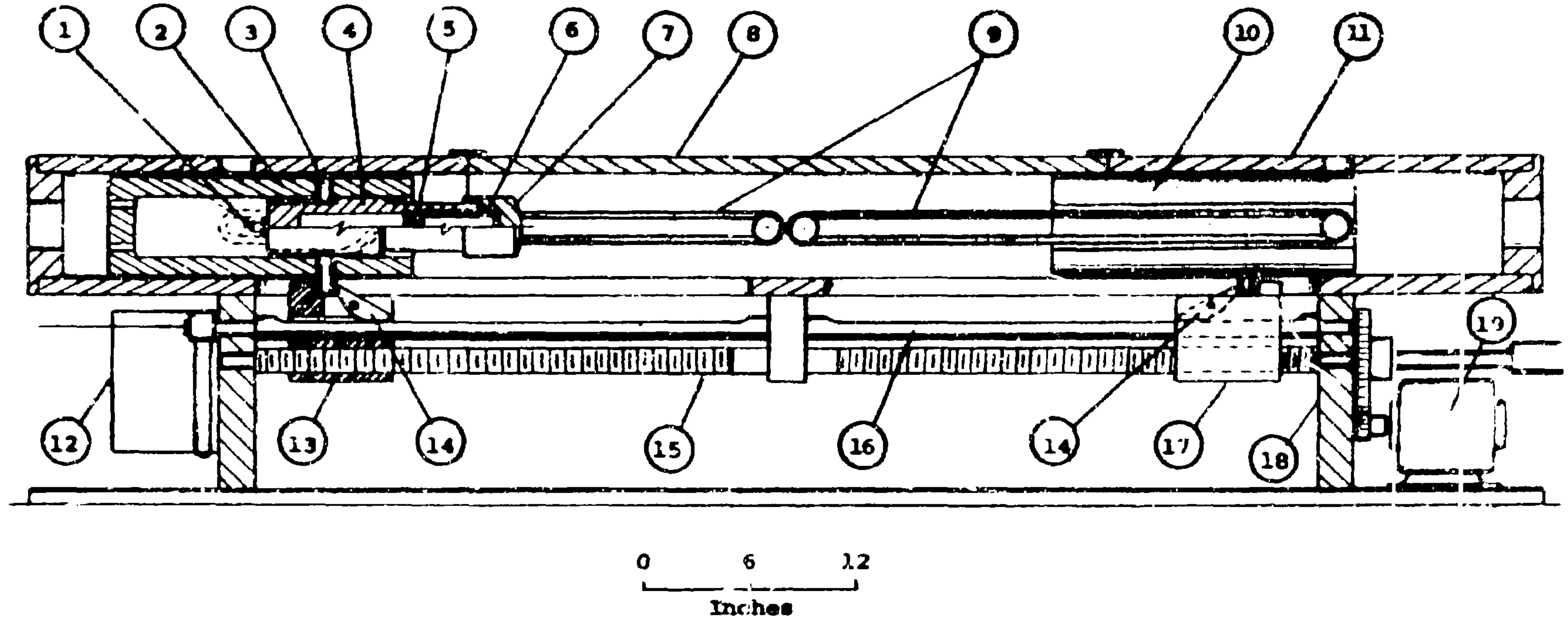
e. The design is not restricted to setback-spin test set applications only; it can be adapted for producing other high velocity impact shocks.



TEST APPARATUS FOR
NWLD TESTS

FIG. A-1 ADAPTER FOR 3"/50 GUN TESTS OF PILOT EJECTION CARTRIDGE



NO.	PART	NO.	PART
1.	Fuze holder stopping pad	11.	Guide tube
2.	Test vehicle	12.	Fast-acting cam shaft actuator
3.	Spin drive key	13.	Test vehicle release mechanism
4.	Shear pin	14.	Release pawl
5.	Helically-grooved fuze holder	15.	Vehicle cocking screw
6.	Test specimen	16.	Release cam shaft
7.	Impact pad	17.	Impact vehicle release mechanism
8.	Access door	18.	Machine frame
9.	Shock cord propulsion loops	19.	Cocking screw power unit
10.	Impact vehicle		

FIG. A-2 SETBACK-SPIN TEST SET MODEL

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

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10. DISTRIBUTION STATEMENT

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

Described is a removable adaptor that is used in the NOL 5-inch Air Gun to produce spin acceleration simultaneously with setback acceleration. The adaptor consists of a rifled breech block and a test vehicle with a 1-foot long spin accelerator (spiraled drive shaft). With the adaptor, the 5-inch gun can impart a peak setback acceleration of 20,000g, a peak spin acceleration of 240,000 rad/sec², and a spin velocity of 50 rps to a 5-pound payload. squared

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14. KEY WORDS	LINK A		LINK B		LINK C	
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SHOCK						
SHOCK TESTERS						
SHOCK - ARTILLERY PROJECTILE						
ENVIRONMENT SIMULATION						
AIR GUNS						

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