AD NUMBER
AD357373
CLASSIFICATION CHANGES
TO: unclassified
FROM: confidential
LIMITATION CHANGES
TO: Approved for public release, distribution unlimited
FROM: Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; DEC 1964. Other requests shall be referred to Directorate of Armament Development, AFSC, Eglin AFB, FL.
AUTHORITY
31 Dec 1972, per doc markings; USADTC ltr, 5 Jun 1979

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ATL-TR-65-10

(Unclassified Title)

AUTOMATIC LIGHT GAS GUN DEVELOPMENT

December 1964

Directorate of Armament Development
Det 4, Research and Technology Division
Air Force Systems Command
Eglin Air Force Base, Florida

Project No. 9850, Task No. 985001

(Prepared under Contract No. AF08(635)-4097
by the Missile and Armament Department,
General Electric Company, Burlington, Vermont)

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FOREWORD

The ultimate military application of this development program, and the present firing results, are classified CONFIDENTIAL. Any narrative which includes specific design information or a detailed description of the concept and its operation is also classified. Drawings and photographs of the weapon, or of its component parts, are in general not classified unless accompanied by a detailed word description of the concept and its operation.

The initial development work, upon which the present phase has built, is discussed in Report No. ATL-TDR-64-25, "Automatic Light Gas Gun Development".

ABSTRACT

This abstract is classified Confidential

Work has been continued toward the development of an automatic hyper-velocity weapon based on the principles and techniques of the laboratory light gas gun. With the basic feasibility of the firing scheme established by the preceding work phase, effort was aimed at advancing the implementation of the concept. Attention was devoted to those aspects of single-shot operation which required improvement or more thorough investigation before a launcher capable of rapid repeated fire could be constructed. Among the areas of consideration were firing cycle time studies, breech mechanism design, revision of launcher dimensions for improved velocity capability, and studies of problem areas encountered in the previous work.

In most respects, good progress was made. Some significant advances toward automatic repeated fire were achieved. However, design ideas and implementation schemes are presently far in the lead of proven firing capabilities. Some of the difficulties encountered in single-shot operation have not yet been eliminated, and these problem areas will require continued study and successful resolution before repeated-fire operation can be attempted.

This technical documentary report has been reviewed and is approved.

DAVID K. DEAN
Colonel, USAF
Chief, Weapons Division

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SECTION I

INTRODUCTION

This report describes a nine months' phase in the development of an automatic light gas weapon. The work is a portion of a continuing effort carried out under contract with Detachment 4, Research and Technology Division, AFSC, Eglin AFB, Fla. Preliminary development was conducted under Contract AF08(635)-2799 and was described in Report No. ATL-TDR-64-25, "Automatic Light Gas Gun Development". The present Contract is AF08(635) 4097.

The ultimate objective of the program is development of a fully automatic weapon based upon light gas launching techniques. In the preceding phase, a basic weapon concept was established and its feasibility explored. The work reported here has built upon this. The concept has been refined and extended, and further progress has been made toward a final weapon.

Four separate but interrelated study areas comprised the project. Analysis, design, fabrication of equipment and fire testing were included in varying degrees among them.

a) Studies were conducted in certain areas unique to the weapon concept and critical to its success.

b) A computer study was conducted for the purpose of defining gun parameter relationships.

c) Variation in weapon performance was considered with regard to a range of variation in projectile weight.

d) Problem areas discovered in the preliminary study and reported earlier were examined in greater detail than had been possible before.

In the sections to follow, each of these phases will be discussed in detail.

For the most part, designs or investigations have been successful, and material progress has been made. This will be apparent in the report. Objective appraisal must be candid, however, and areas in which difficulties still exist or where new problems have been encountered are carefully analyzed.

SECTION II

CRITICAL AREAS AND BASIC TECHNIQUES

The present concept for an automatic light gas gun requires unique or unusual design solutions in several areas. Where these were outside common gun technology, special designs were developed and equipment built. The following paragraphs summarize the work in these areas.

BREECH MECHANISM

The equipment used in Phase I for establishing feasibility was designed for single shot operation. As a matter of convenience, available hardware was used. The M61 bolt and rotor parts and Government furnished pneumatic chargers are examples of adaptations employed. The equipment worked satisfactorily and was useful for its purpose.

In the present study, a design capable of repetitive fire was required. For reasons which will be discussed later, recoilless operation was desired. Further, a mechanism was needed which would be compatible with an envisioned rapid fire weapon concept.

Review of weapon functioning established two requirements: 1) it was necessary that all segments of the complex firing cycle be carefully timed and regulated, and 2) it was necessary that ejected debris be expelled straight to the rear. It was felt that an external cam would provide the simplest and most positive control of the firing sequence. The possibility that multiple barrels might ultimately be used, all sequenced with respect to one another, makes this additionally desirable. An electric motor driving a programming cam was selected as the most direct design approach. The cam controls bolt motion and lock action. It can also be adapted to perform sequential switching operations at desired times.

A breech mechanism was designed around this principle of cam control. The overall assembly layout is shown in Figure 1; and the photographs shown in Figures 2, 3, and 4 depict the equipment. Features of the various components will be described separately.

Bolt and Lock

A two-piece articulating bolt was designed which would permit direct rearward ejection of debris. The bolt head contains the electrical firing contact and serves as the primary structural element for absorbing firing loads. Notches at the side of the bolt permit locking. The bolt incorporates an extractor for controlling and extracting a fired case. Four rollers which engage tracks in the receiver assembly guide the bolt, while a fifth roller is

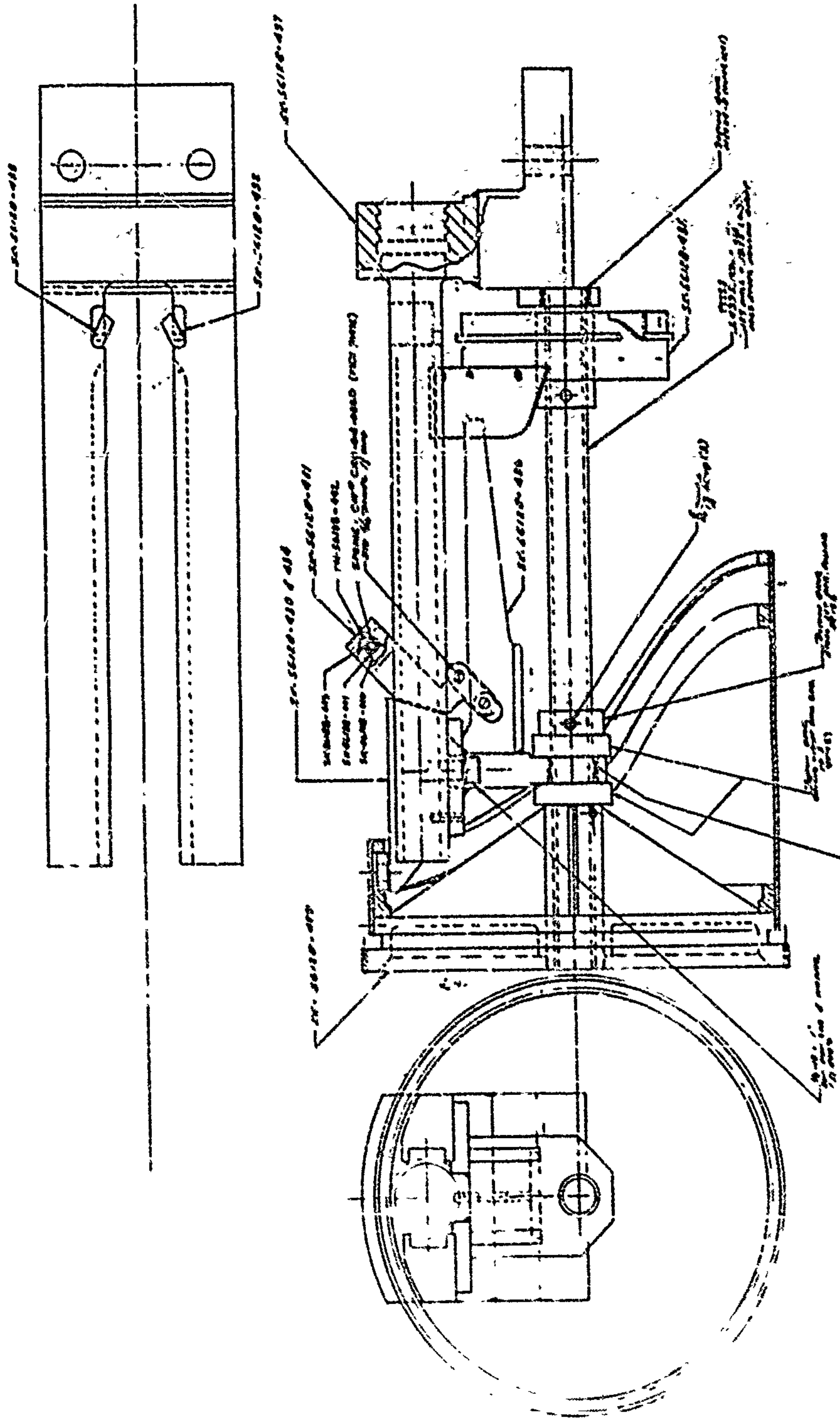


Figure 1. Design Layout of Breech Mechanism

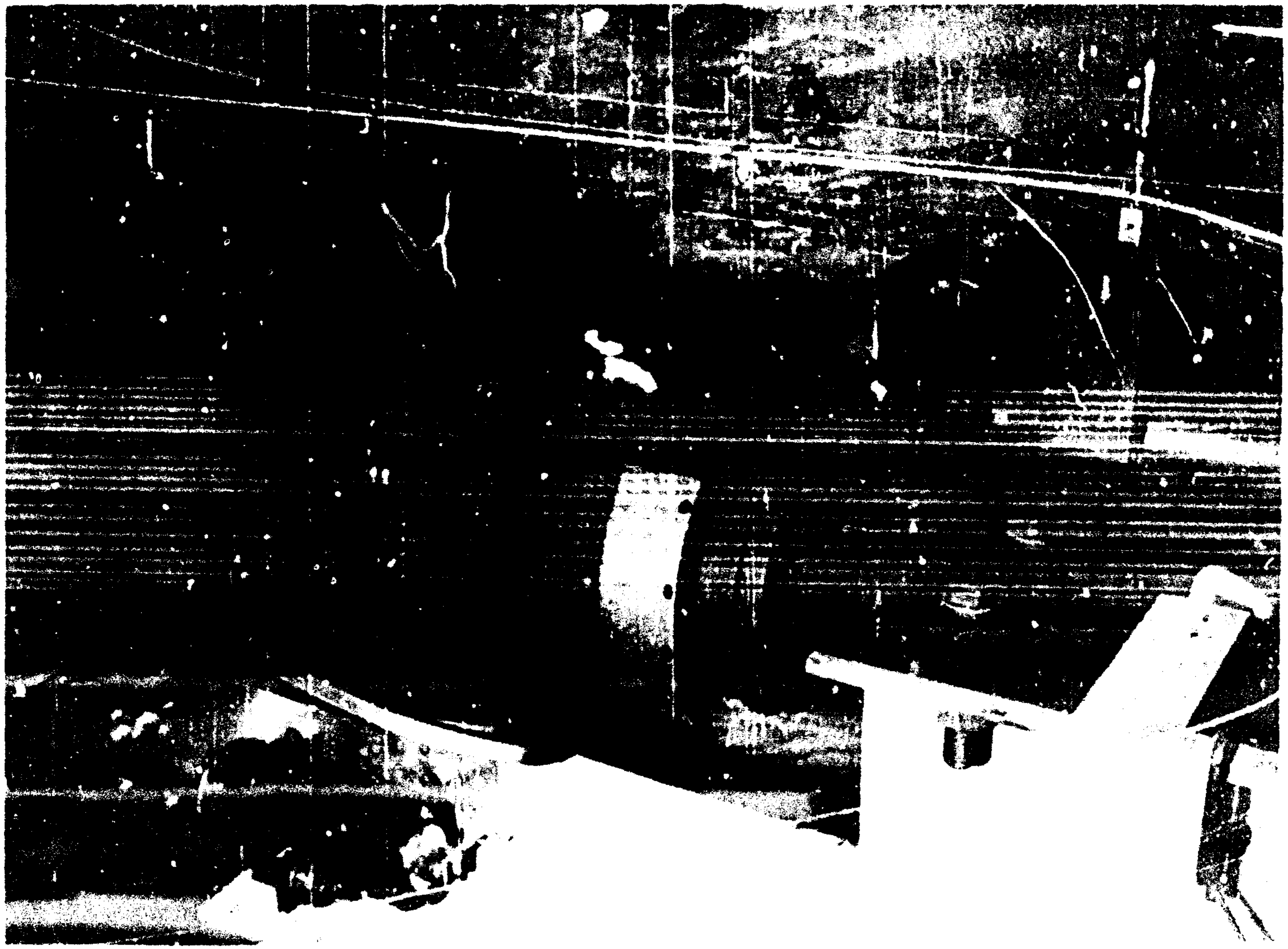


Figure 2. Cam-Operated Breech Mechanism, Showing Bolt Head in Raised Position

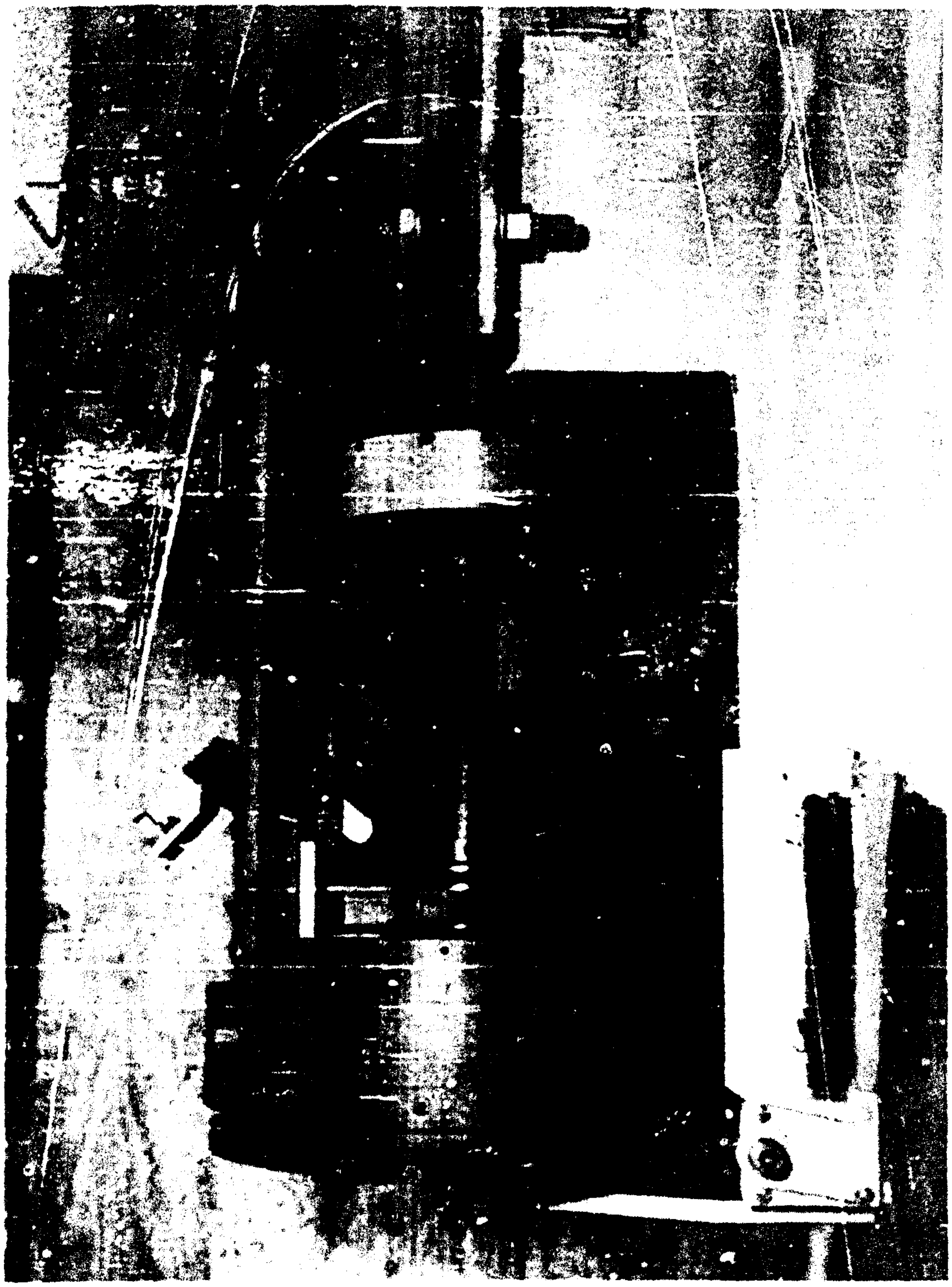


Figure 3. Breech Mechansim, Side View

Figure 4. Breech Mechanism, Rear View, Showing Bolt Opening for Ejection of Debris

provided at the top of the bolt to serve as a cam follower. The bolt head is the forward articulating portion of the bolt: The rear bolt body is a hollow square tube.

In action, the bolt carries a round forward into the chamber. The two lateral lock blocks, actuated from below by a small second cam, secure the bolt head in firing position. After firing, the main cam drives the bolt rearward. As the bolt continues rearward beyond its feed position, the bolt head is rotated upward by cam action. This clears the bore centerline and provides unobstructed passage for the debris through the bolt body.

Simultaneously with the rise of the bolt head to clear the bore centerline, the extractor is cammed downward. It was originally intended that the spent case or unfired round should carry straight to the rear on its own momentum. Experience has shown that gravity drop causes the case to stay with the extractor and not eject properly. For the present tests, the bolt head was modified to permit the bolt to hurl the case "over-the-shoulder", so-to-speak, that is, through an arc above the bolt. This is a temporary measure and a means of expelling the case to the rear will have to be provided in the future.

After the ejection cycle, the bolt is moved forward into feed position to pick up a new round.

Cam

The main cam is a 12-inch diameter cylindrical cam with a single groove for driving the bolt. The cam profile has three dwells with appropriate transition curves between. The forward dwell is the firing position. This dwell is longer than for most rotary weapons in order to allow for the added time required for helium injection. The intermediate cam dwell is the feed position. Here the bolt head is down to receive a round. The most rearward dwell is the ejection position, where the bolt head is raised, as described above. Figure 5 shows the main cam layout.

The main cam is driven by a 196 tooth, 16 pitch gear, machined into the cam's outer surface. It is centrally mounted on a shaft which also supports the locking cam. Besides providing locking action, the locking cam incorporates a support surface, which appears beneath the round as the round is chambered to prevent it from falling through the receiver.

Support

The cam and bolt assembly are supported in a heavy receiver section. This is essentially a heavy bracket into which the barrel, or pump tube breech, is locked. The bracket incorporates two heavy side rails, appropriate bearing supports and a linear cam for controlling bolt head action. The support is visible in the previously referenced photographs and drawings.

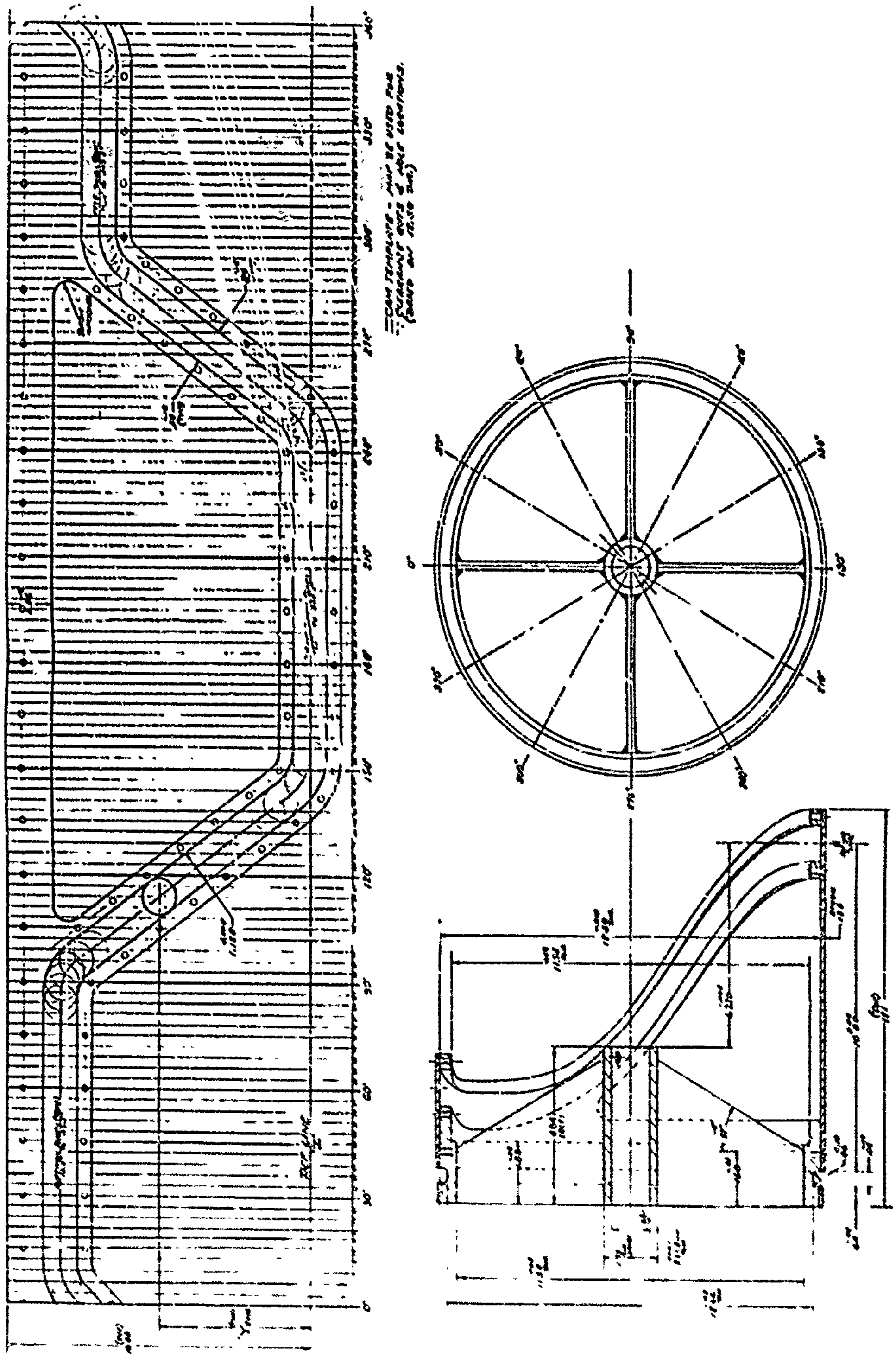


Figure 5. Design Layout of Main Cam

Multiple Barrel Adaptation

The support has been designed to accommodate a single firing barrel. Design investigation shows that the main cam, at its present size, could accommodate as many as eight firing barrels. Moreover, the existing cam could serve these additional barrels without requiring any major design change, since the action for each barrel assembly is identical to that for a single barrel.

REDESIGN OF OTHER COMPONENTS

In preparing the equipment for the present series of tests, several of the old components were redesigned for improved performance as follows:

a) The ejection shuttle valve at the muzzle was changed to incorporate an external spindle and spring. This was done to permit attachment of a motion transducer so that the motion of the internal spool (or shuttle) could be recorded during fire testing. Basic valve action and internal spool design were unchanged in principle. The shuttle valve is shown in Figure 6, attached to the barrel in firing position.

b) The coupling, or high-pressure section, and its junction with the launch tube, were altered for the current tests. During previous tests the launch tube engaged the high-pressure coupling in a long slip fit. After firing, the tube could not be separated from the coupling, and close inspection of the forward breech was difficult. In the new equipment, a joint was provided in the high-pressure breech at the junction of the conical carrier seat and the straight cylindrical pump tube. The objective was to permit uncoupling of the two components at the area of most interest. This would facilitate inspection after firing. Figure 7 is a cross sectional drawing of the launcher, showing the coupling region. Figure 8 is an enlarged view of the high pressure section.

The new junction design has had mixed success. The parts can be disassembled after firing and breech inspection and subsequent rework is much more easily accomplished than previously. However, sealing and material deformation are problems. Pressures proved too high for the metallic C-ring seals used with success in other sections of the gun. Worse, in the initial design, the small escape route opened to the gas, as deflection occurred during firing and the parts separated ever so slightly, caused carrier failure as the gas rushed out to the C-ring seal. Carriers were split cleanly by the pressure differential created by this gas flow on the first three rounds fired. Effective sealing was finally achieved by recessing a stainless steel ring into the bore surface at the joint between the coupling and the launch tube so as to cover the crack. (See Figure 8) However, even

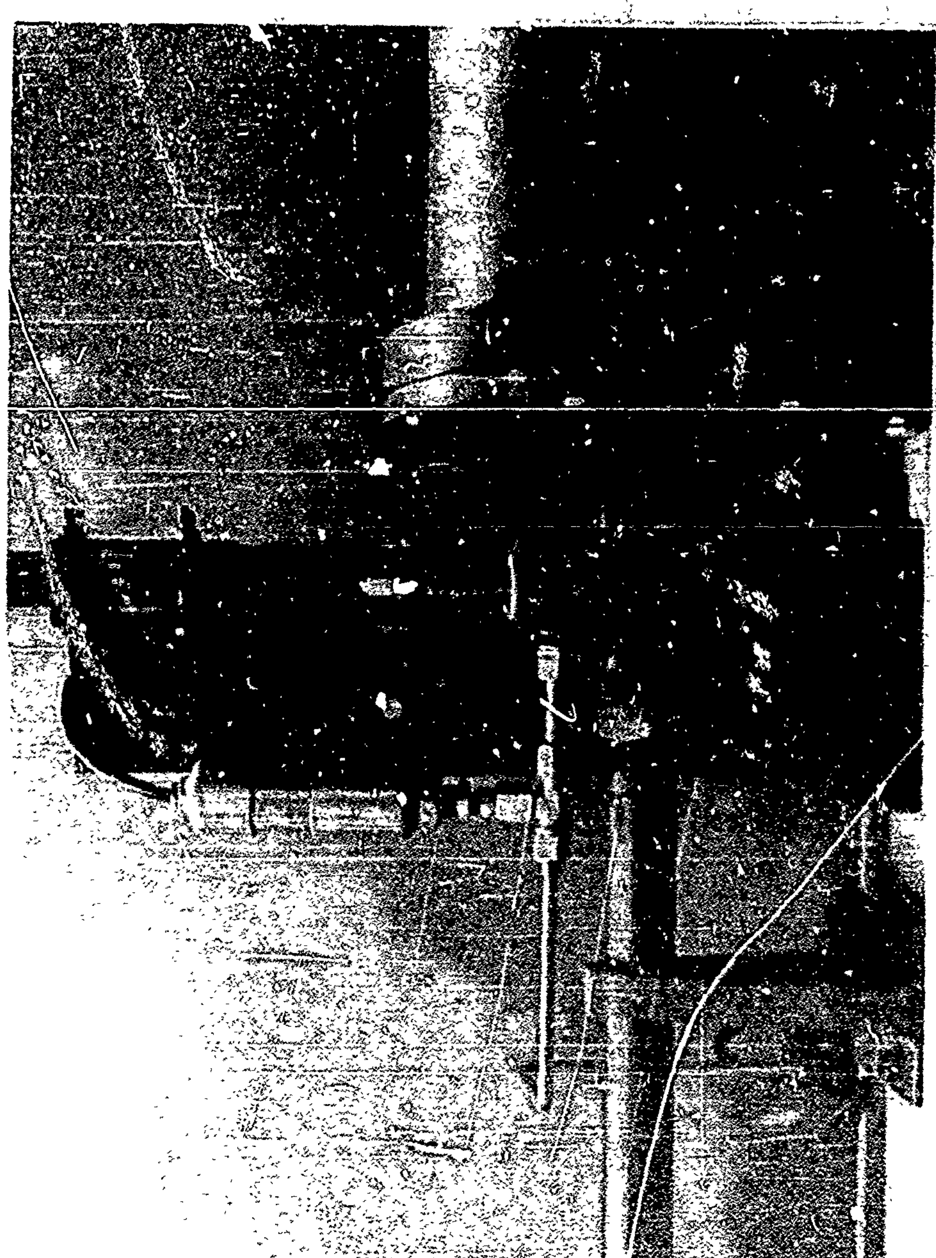


Figure 6. Shuttle Valve With Attachments for Monitoring Ejection Pressure and Shuttle Motion

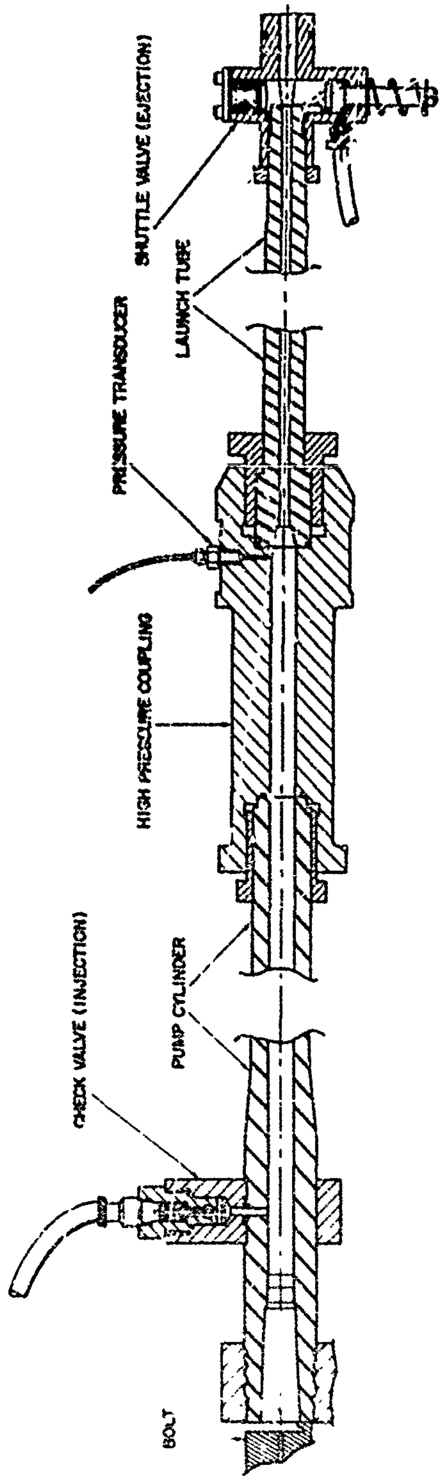


Figure 7. Cross-Sectional Drawing of Launcher

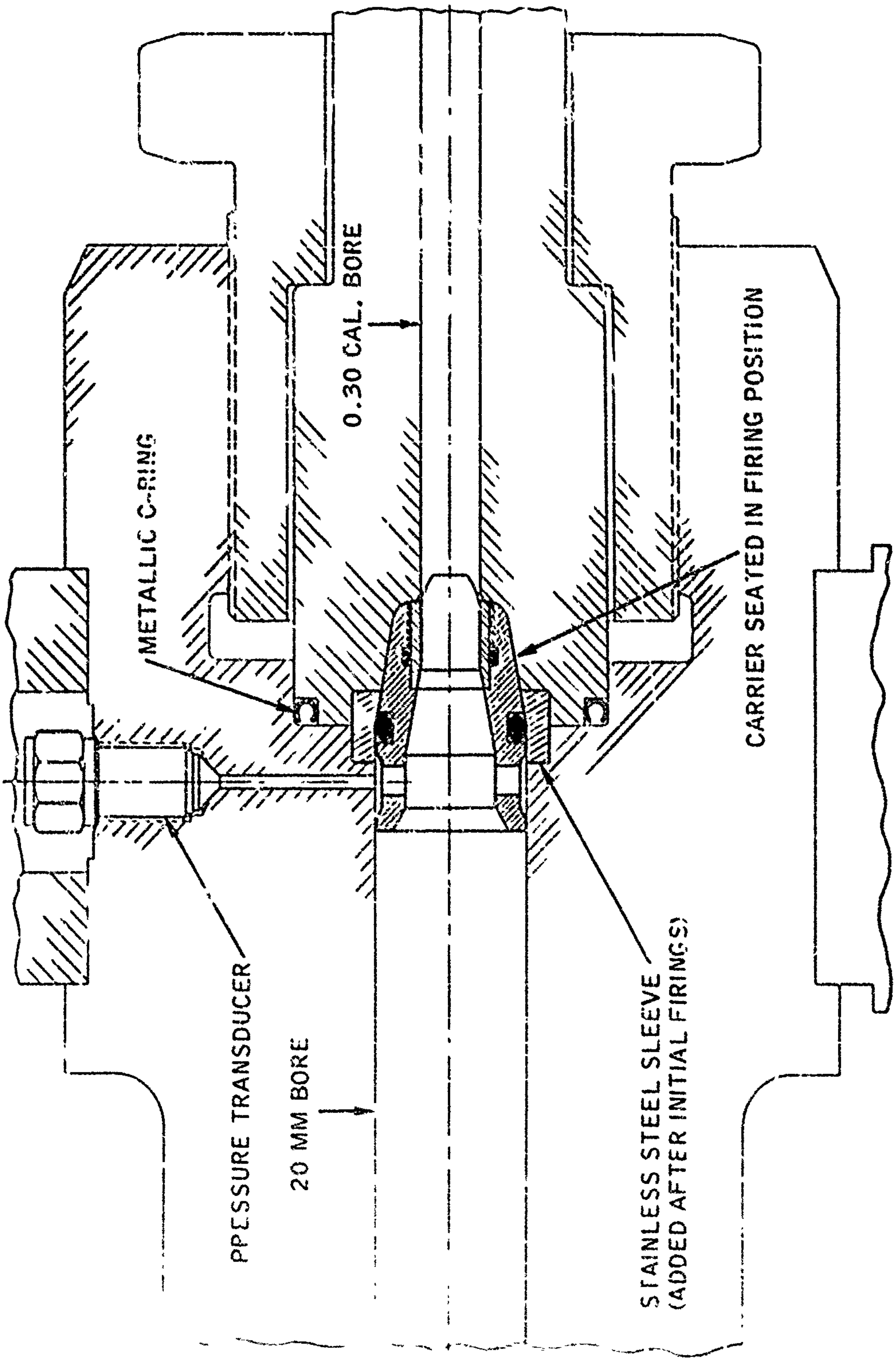


Figure 8. High-Pressure Section (Detail)

this has not been a completely satisfactory solution. Unequal expansion of the two parts during firing causes gradual bending of the ring. A new one-piece high-pressure section should be substituted in future tests.

c) A minor change was made to the check valve. In past firings the flat spool face had gradually become dished until leakage occurred. This part should provide the primary gas seal, and its flatness is necessary for proper valve functioning. The thickness of the face disk was increased for greater strength. No further warping has been observed. Photographs of the breech mechanism assembled with the other parts of the gun in firing configuration are shown in Figures 9, 10, and 11.

FIRING SEQUENCE TIMING

A complete firing cycle is comprised of separate sequential operations. These must be linked together in a controlled manner if automatic operation is to be successful. Thorough knowledge of the time required to complete the various individual functions and an understanding of their interdependencies are necessary. One phase of the current work has considered this requirement in detail. It will be helpful to review a firing cycle before beginning a detailed discussion.

Assume, as a starting point, the bolt in feed position. Further, assume a round has been fed into the receiver ahead of the bolt. The bolt is at the end of the feed dwell; forward motion is imminent. The sequential steps which constitute a firing cycle are, in order:

a) Feed stroke: The bolt moves forward, chambering the round.

b) Bolt locked.

c) Injection: The injection solenoid valve is energized, opens and gas enters the pump tube. The carrier is driven into firing position. Gas continues to flow until full charge pressure is reached.

d) Fire: The primer is energized, propellant burns, the piston is driven down the pump tube, the projectile shears and is propelled out the launch tube.

e) Bolt unlocked.

f) Case extraction: The bolt moves rearward, extracting the case. At a point near the limit of bolt travel, the articulated bolt head lifts to clear the ejection path. Ideally, the case continues rearward in an uninterrupted motion. As has been mentioned, the case is flipped

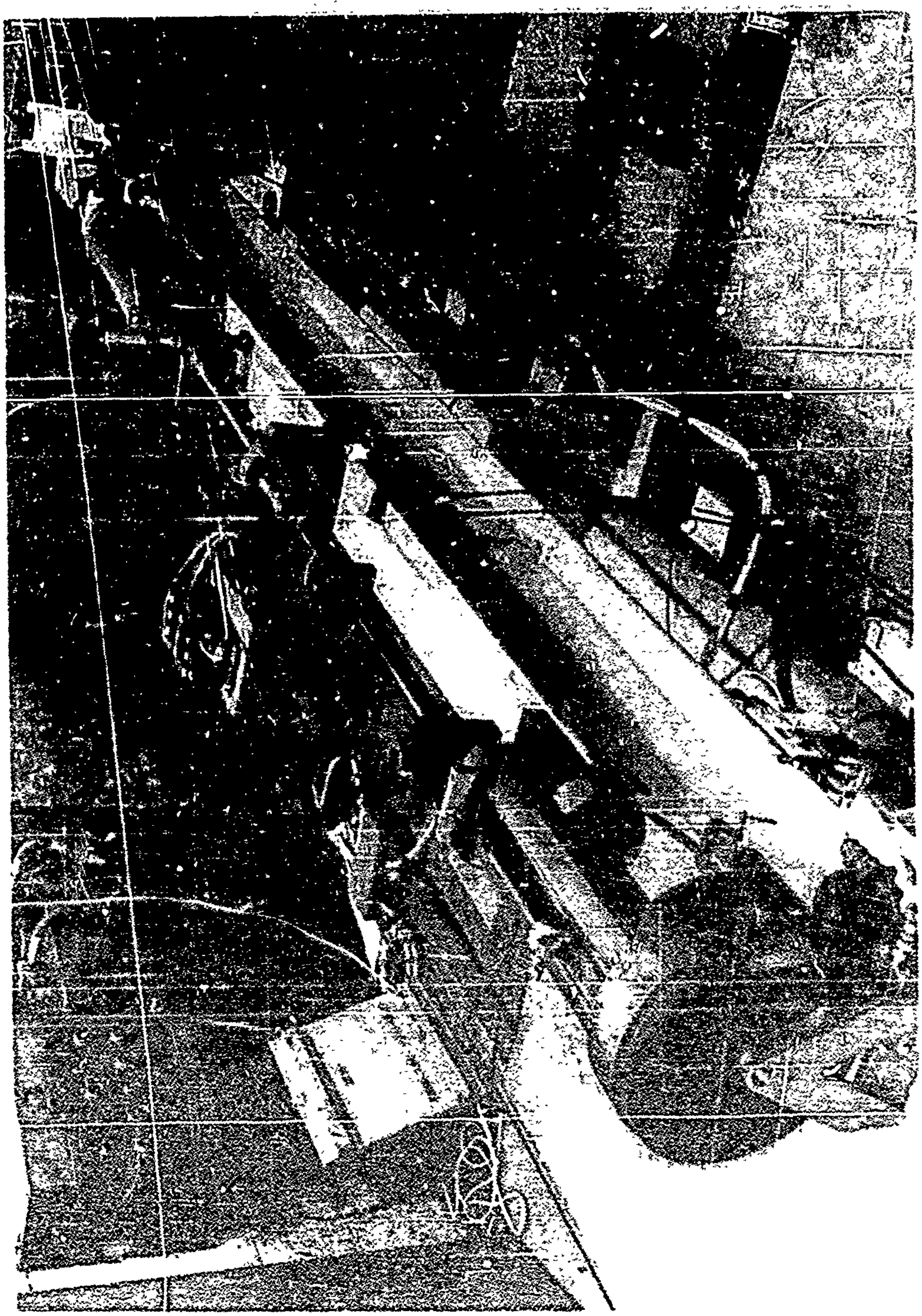


Figure 9. Assembled Launcher and Test Equipment

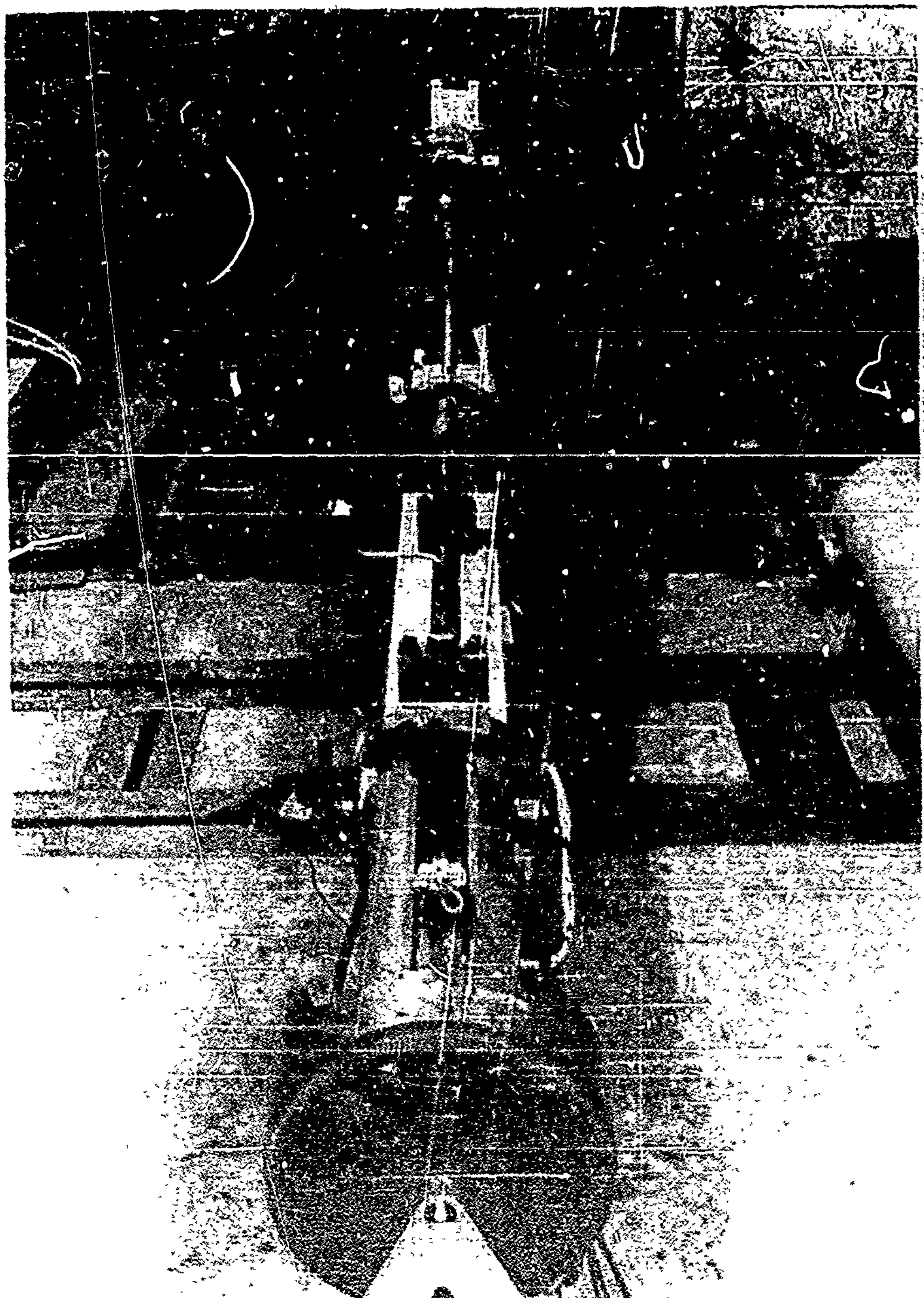


Figure 10. Assembled Launcher, Rear View

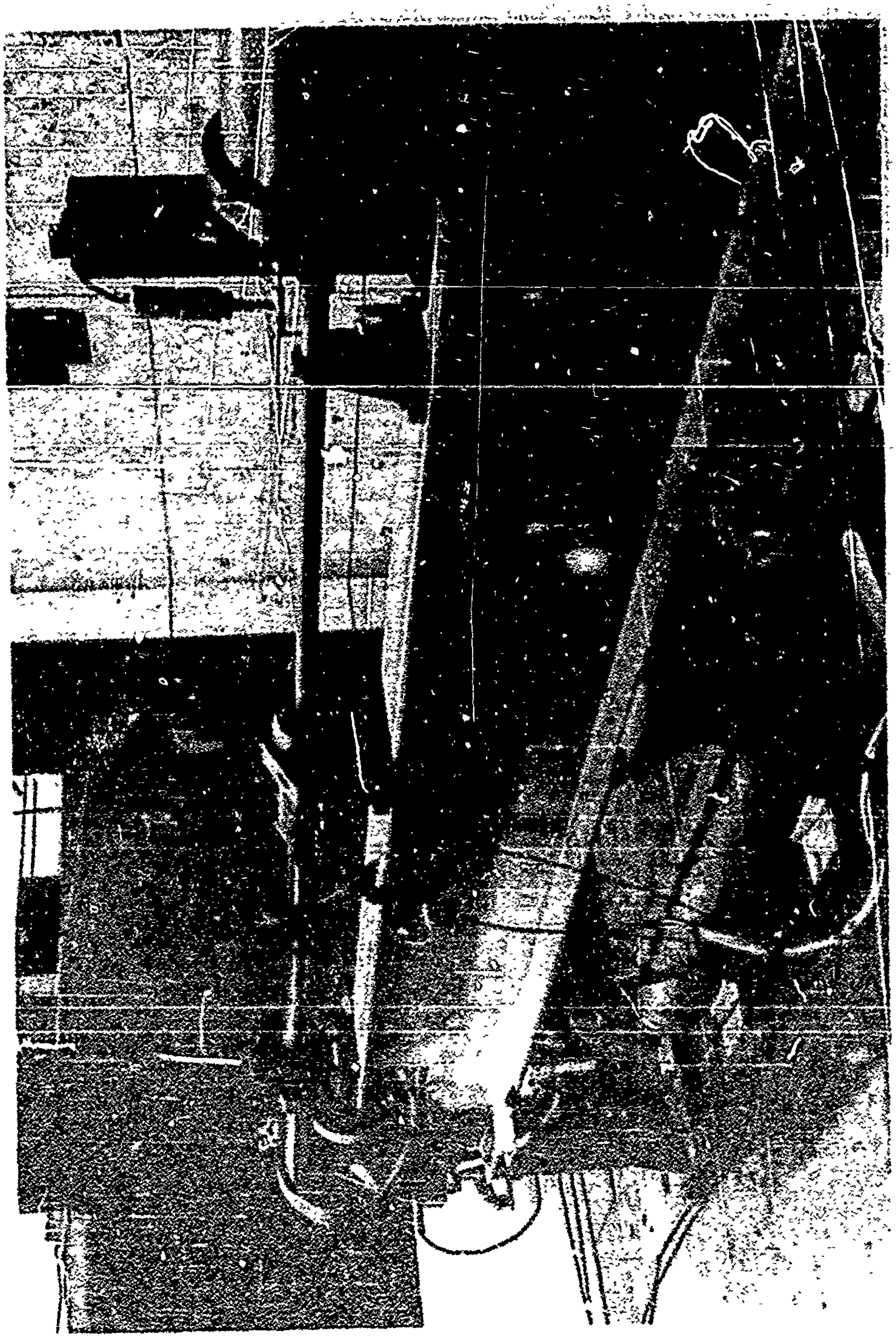


Figure 11. Assembled Launcher, Front View

upward by the bolt in the mechanism's present stage of development.

g) Ejection: The ejection supply valve is energized. Ejection gas enters the shuttle valve, drives the spool across the muzzle, enters and travels up the launch tube bore, and forces the expended piston and carrier rearward through the pump tube. These are expelled from the chamber and pass through the bolt body opening.

h) Position bolt to feed position: The cam moves the bolt forward from ejection position to feed position.

In synthesizing a complete firing cycle from these operations, each respective time requirement must be determined. This has been the object of the firing sequence timing study.

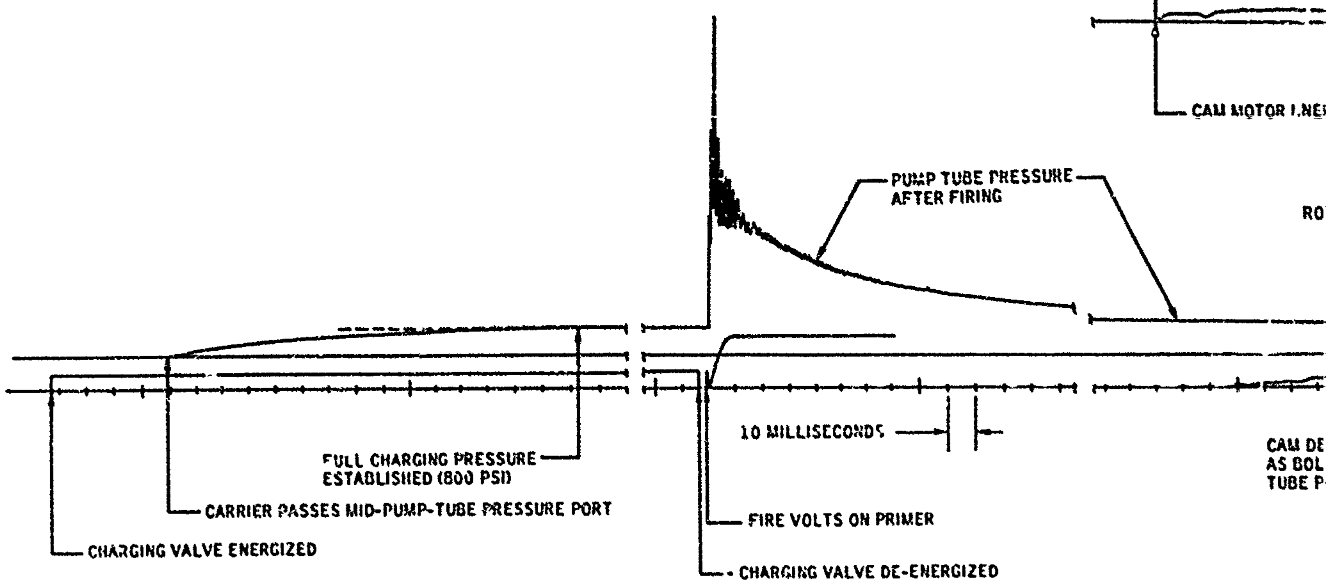
Estimates of sequence times can be drawn from several sources. Some operations, such as chambering the round, are common weapon practices and their time requirements can be inferred from past experience. Measurements of injection time and ejection transit times have been made previously in the laboratory, and these figures are already available. Finally, specific data have been taken from the instrumented firing tests. This is the most dependable information, since it is derived from the actual equipment in operation. A typical firing record is shown in Figure 12.

Sequential operation time requirements are summarized in Table I. Operations are broken down into subdivisions where appropriate, and the source of the data is indicated in each case.

One interesting aspect of the timing data is observable in Figure 12. Records taken during firing tests indicate that the pressure of the residual propellant gas decays slowly. The gas is trapped between an expended piston at the forward end and a somewhat crumpled and distorted case at the breech. Pressure decay has been assumed rapid, but firing records and observed bolt damage indicate that such is not the case.

Since it is undesirable to introduce a pause of several hundred milliseconds to wait for pressure decay, the pump tube must be vented. The most sensible way is to simply force open the bolt under pressure; this was done in the firing tests.

Two effects were observed. The bolt roller, a light ball bearing, had not been designed with this load in mind, and its outer case cracked occasionally. This can be easily remedied with a stronger bearing or a solid roller. More significantly, the force of the expanding gas against the bolt face during extraction appreciably accelerated the cam. This suggests the possibility of a self-driven or at least self-assisting gun.


CAM MOTOR ENE
PUMP TUBE PRESSURE AFTER FIRING
RO
10 MILLISECONDS
CAM DE
AS BOL
TUBE P
FULL CHARGING PRESSURE ESTABLISHED (800 PSI)
CARRIER PASSES MID-PUMP-TUBE PRESSURE PORT
CHARGING VALVE ENERGIZED
FIRE VOLTS ON PRIMER
CHARGING VALVE DE-ENERGIZED

1

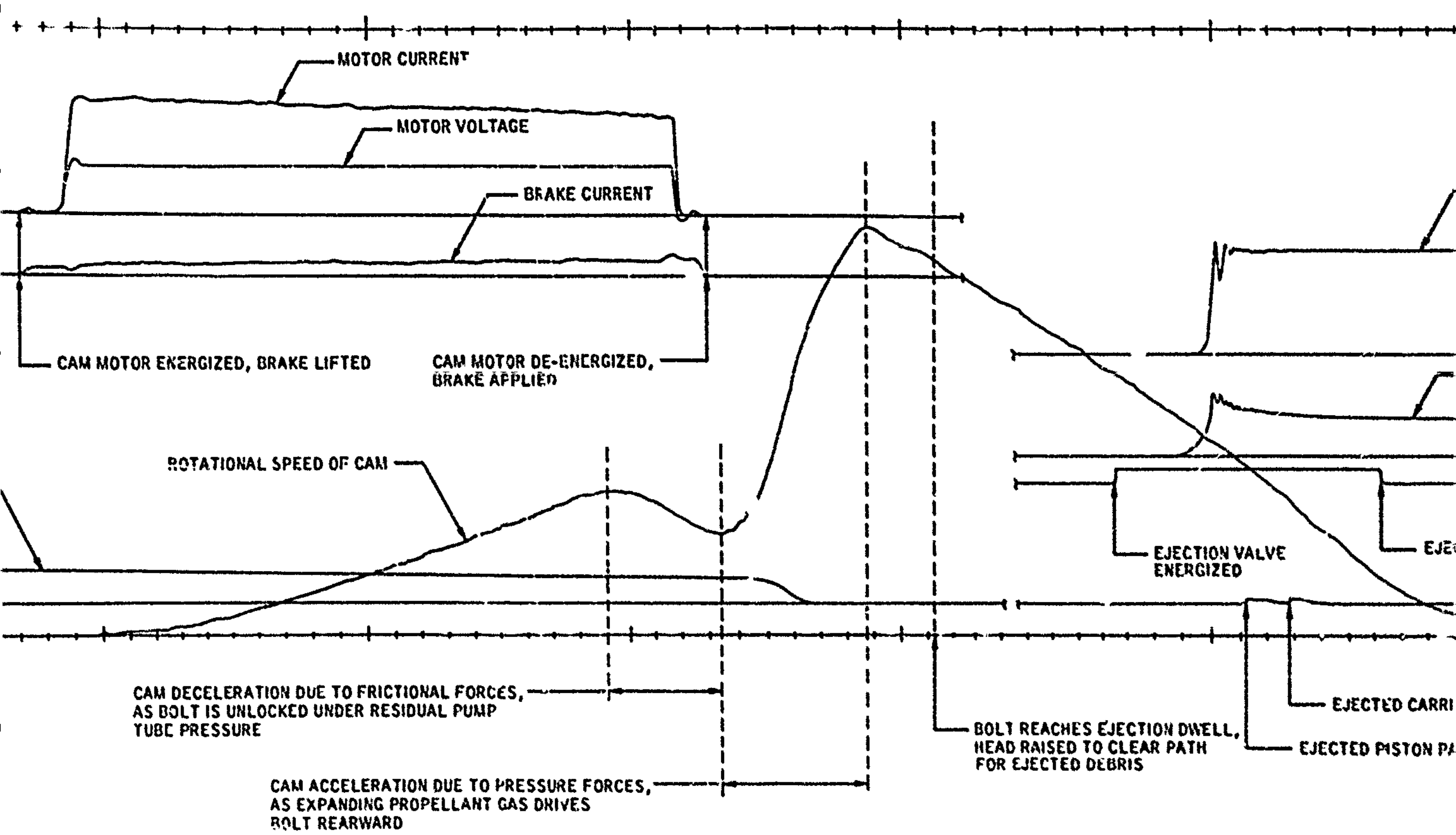


Figure 12. Oscillograph

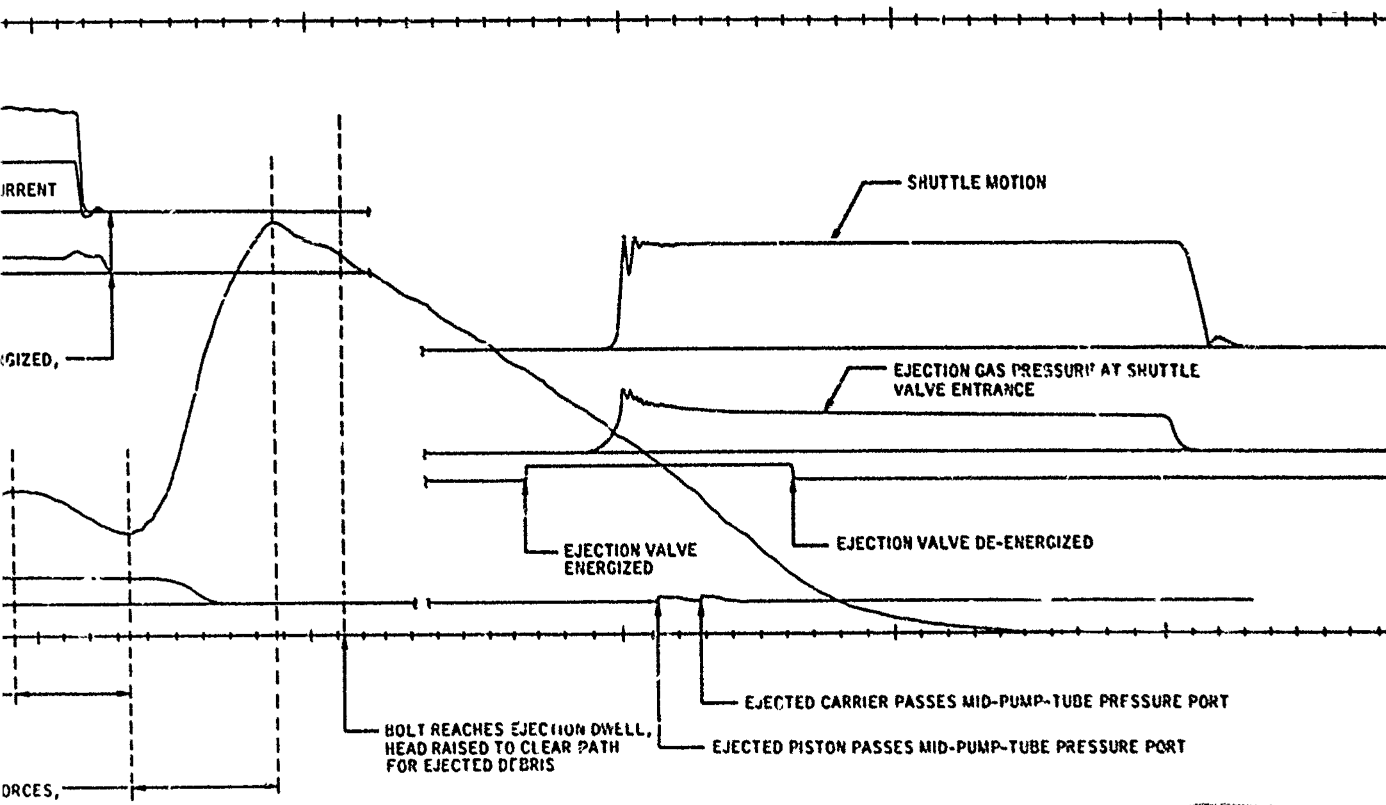


Figure 12. Oscillograph Record of Firing Cycle (Condensed)

Table I. Firing Sequence Time Intervals

Sequence	Time Interval (Milliseconds)	Basis For Estimate
Feed Stroke	30	M61 design practice
Bolt Lock	5	Cam design
Injection		
Solenoid Valve Delay	12	Laboratory test; fast opening solenoid valve; no check valve
Carrier Motion	20	Laboratory test, maximum. Less for high charge pressure
Charge Pressure Rise	200	Fire test with check valve, slower acting valve than above
Firing	3	Fire test. Time from primer voltage to projectile coil signal
Bolt Unlock	5	Cam design
Extraction	36	Cam design, based on M61 practice
Ejection		
Solenoid valve energized to piston at mid-barrel port	50	Fire test; carrier not ejected with piston
Total ejection time estimate	60	Estimated from fire test data
Laboratory ejection time	(50)	Laboratory test without shuttle valve. Basis for estimate, but should not be added thereto
Return Bolt to Feed Position	12	Cam design

The total time requirement for a single firing cycle need not necessarily be the sum of all the separate time intervals. Some operations can be performed simultaneously to telescope the total elapsed time. For example, ejection can be initiated before extraction is complete, so long as the ejected piston and carrier do not arrive at the bolt before the bolt head is raised.

Gas flow is obviously the biggest time consumer among the several operations. The charge pressure build-up interval is 200 milliseconds, the largest single item. This results from the fact that check valve design and solenoid valve selection were not predicated on a need for particularly fast action or high rate of flow. It was originally expected that mechanical, rather than pneumatic, processes would establish the primary limitations on cycling rate.

In future work, special attention will be accorded the gas flow problem. Fast opening charging valves will be used, in parallel array if necessary. The check valve design will be given particular attention. Operational requirements are severe, since it is necessary to seal against full chamber pressure as the propellant burns. Nevertheless, a larger port area is obviously needed, and various means of obtaining this will be examined.

The total cumulative time for the sequential functions in Table I is 433 milliseconds. About half of this is represented by charge pressure rise. In light of previous comments, it should be possible to shorten the overall time considerably. A total firing time of 300 milliseconds seems a reasonable goal for a weapon.

RECOILLESS OPERATION

Space vehicle application is contemplated for the light gas weapon. In such an installation, recoil forces might prove undesirable. Vehicle structures are characteristically light-weight and are not designed for high forces. In addition, excessive momentum change might have adverse effect on orbit path. Recoilless operation would seem a desired characteristic for any such weapon installation.

For the light gas weapon, the mass of the fired projectile is much smaller than that of the ejected debris, which consists of cartridge case, piston and carrier. Although firing velocity is much higher than ejection velocity, the mass ratio tends to compensate. Quite possibly, momentum could be made to balance. This has been briefly investigated.

A primary consideration in balancing momentums is co-linearity of the velocity vectors. To properly balance a projectile fired in a forward direction, compensating mass should be fired along the same line in the opposite direction. Ejection of matter in any other direction, to the side, for example, will not achieve momentum balance. This is the reason behind the articulating bolt design, which allows ejection straight to the rear.

During each firing cycle, two masses are discharged in the forward direction: the projectile and the helium gas which drives it. Projectile weights from 5-50 grains are fired. Helium mass might be as high as 70 grains, depending upon charge pressure and pump tube length. Available to balance against these are the masses of the cartridge case, piston, carrier and propellant gas. Nominal values for these are 1875 grains for the case, 430 for the Lexan/aluminum piston, 200 for the carrier, and about 400 for the propellant charge. A 25 to 1 ratio, or greater, is therefore typical between the weights of ejected debris and combined projectile and helium. To compensate for a 15,000 ft/sec. muzzle velocity, ejection velocities of a few hundred feet per second would be adequate.

Ejection velocities of 300-400 ft/sec. for piston and carrier have been measured in laboratory tests with an ejection gas pressure of 1,000 psi. These velocities are of the desired order of magnitude, and they offer encouraging support for the idea.

A detailed analysis of recoil reduction was planned when the program started. As work progressed, it became clear that a thorough study would be premature. No specific projectile mass has yet been established, nor has optimum muzzle velocity been set. Rather, the project is at the stage where ranges of values are being studied for the various gun parameters.

For these reasons, a six-degree of freedom analysis and instrumented firing measurements of recoil force which had been planned were postponed to a later stage of the development program.

SECTION III

PARAMETER OPTIMIZATION STUDY

Since velocities only slightly in excess of 10,000 ft/sec. had been attained with the previous launcher, and since both the initial helium pressure and the peak compression pressure had been higher than was desirable for other aspects of the firing, it was felt necessary to adjust the new design parameters to achieve more favorable performance characteristics. By improving the balance of parameters at this stage of the mechanism development, all aspects of the design could be brought into a closer relationship to the final weapon.

In determining which performance characteristics should be regarded as optimum for the weapon, primary consideration was given to high muzzle velocity and minimum system weight. Other desirable characteristics were felt to be:

a) Minimum barrel lengths compatible with high velocity performance.

b) Minimum overall bulk and dimension of the weapon system.

c) Low initial helium pressure: to minimize carrier deformation upon charging impact and to obtain the greatest number of firings from a given supply of compressed helium.

d) Low peak pressure: to minimize bore enlargement and barrel wear in general.

e) Relatively low piston mass: to minimize total ammunition weight, and to facilitate pneumatic ejection.

Contract specifications called for a projectile mass of between 5 and 50 grains; projectile material and caliber were not specified.

Considering the complexity of the light gas gun firing cycle, and the number of variable parameters involved, it was felt necessary to optimize the launcher configuration using computer programs developed to simulate the firings, rather than by trial-and-error experimentation. A survey of existing computer programs was made to select three or four which appeared most promising in terms of accuracy, availability, and cost.

It was decided to conduct the major part of the study at the U.S. Army Ballistic Research Laboratories, Aberdeen, Md., using the most advanced and comprehensive of the B.R.L. light gas gun computer programs. This program, developed by Paul G. Baer of the Interior Ballistics Lab, utilizes the Richtmyer-Von Neumann "q" method of flow representation, which is capable of closely simulating the propogation and reflection of shock waves characteristic of a light-piston type launcher. Details of the program, its underlying assumptions and the basic equations, are discussed in Reference 1.

In order to increase the reliability of the simulations, open-end calibration firings were made to determine piston muzzle energy for various values of piston mass and propellant charge. This experimental data was then used as a reference for adjusting the computed burning phase of the simulation. Since the propellant used to drive the piston was a commercial small arms propellant (DuPont IMR4198), its thermochemical properties were not as completely and precisely determined as those of most military propellants. In particular, no data was available on the linear burning rate of the propellant, which is an important parameter in the computation. Therefore, a number of preliminary computer runs were made, using the standard interior ballistics program, to determine which assumed values of burning rate, piston shot-start pressure, and average resistive pressure resulted in the best agreement with the calibration firing data. The values thus determined were then used for the burning phase of the light gas gun computations.

A total of twenty-seven simulated firings were run on the B. R. L. computer. The input conditions and the results are summarized in Table II. Referring to this data, it may be seen that certain trends are clearly established for the general range and balance of parameters considered in this study. First of all, a comparison of runs 3 and 4 indicates the magnitude of the performance increase achieved by increasing the base area of a given-mass projectile, all other parameters remaining fixed. That the increase occurs is hardly surprising, but the extent of the improvement is striking. Still larger calibers were not tried, since at these diameters metallic projectiles had to be either very short or hollowed out if the projectile mass was to be kept down. Furthermore, there was a practical limit to the amount that the projectile could be shortened or hollowed and still perform properly. A projectile diameter of 0.30 inch was chosen as the maximum practical limit (and hence the optimum) for the present launcher and the given range of projectile mass values.

Other trends noted were the beneficial effects of increasing pump tube length and piston mass. It was discovered that with all other parameters held constant, the effect of increasing the length of the pump tube was to increase the ratio of muzzle velocity to peak helium pressure. Stated differently, for a given limiting peak pressure, a higher muzzle velocity can be achieved with a longer pump tube. In Figure 13 the results of nine of the simulations are plotted to illustrate this pattern. (Of course this trend would reach a limit for the present configuration, and might not apply at all to some other configurations, but over the range of parameters considered, the generalization is valid.) A similar pattern was found to exist with regard to piston mass. for a given limiting peak pressure, a higher muzzle velocity

Table II. B. R. L. Computer Study

Projectile	Run No.	x_p (in.)	p_1 (psi)	p_e (psi)	m_s (gram)	$p_{max.}$ (psi)	V_{muzzle} (ft/sec)
0.22 Cal. Projectile, m_p = 17.9 gm., m_c = 400 gr.	1	50	1000	20,000	1.0	238,680	11,505
	2	70	475	20,000	1.0	(exceeded limit)	---
	3	70	600	20,000	1.0	222,486	11,079
0.30 Cal. Projectile, m_p = [illegible]7.9 gm., m_c = 400 gr.	4	70	600	20,000	1.0	162,696	14,843
	5	70	550	20,000	1.0	174,223	15,084
	6	60	550	20,000	1.0	191,717	15,576
	7	50	550	20,000	1.0	223,306	15,776
0.30 Cal. Projectile, m_p = 27.9 gm., m_c = 360 gr.	8	50	550	20,000	1.0	247,930	17,676
	9	60	550	20,000	1.0	198,695	17,065
	10	60	550	5,000	1.0	198,372	16,887
	11	60	550	100,000	1.0	(exceeded limit)	---
	12	40	700	20,000	1.0	(exceeded limit)	---
	13	40	1000	20,000	1.0	218,052	15,769
	14	40	900	20,000	1.0	(exceeded limit)	---
	15	40	1100	20,000	1.0	213,680	15,391
	16	50	700	20,000	1.0	217,296	16,619
	17	50	850	20,000	1.0	196,271	15,771
	18	60	400	20,000	1.0	(exceeded limit)	---
	19	60	700	20,000	1.0	186,336	15,94[illegible]
	20	50	700	20,000	2.0	(exceeded limit)	---
	21	50	700	20,000	3.0	(exceeded limit)	---
	22	60	700	100,000	1.0	(exceeded limit)	---

Table II. B. R. L. Computer Study (Cont)

	Run No.	x_p (in.)	p_1 (psi)	p_e (psi)	m_s (gram)	$p_{max.}$ (psi)	V_{muzzle} (ft/sec)
0.30 Cal. Projectile m_p = 27.9 gm. m_c = 360 gr.	23	40	950	20,000	1.0	219,144	15,968
	24	50	1000	20,000	1.0	185,767	14,895
	25	60	175	20,000	1.0	225,071	17,702
	26	50	1000	20,000	2.0	219,176	11,351
	27	50	1000	20,000	3.0	214,563	9,242

Definition of Symbols

m_p = mass of piston

m_c = mass of solid propellant charge

x_p = pump tube length

p_1 = initial helium pressure

p_e = projectile shot-start pressure

m_s = mass of projectile

$p_{max.}$ = maximum helium pressure reached during firing

V_{muzzle} = muzzle velocity of projectile (evacuated bore)

Remarks

1. DuPont IMR4198 propellant properties used.
2. A pressure limit of 250,000 psi was assigned to the computations.
3. Projectile bore friction was represented by an equivalent "average resistive pressure" of 500 psi.
4. The launch tube bore was assumed to be evacuated before firing.

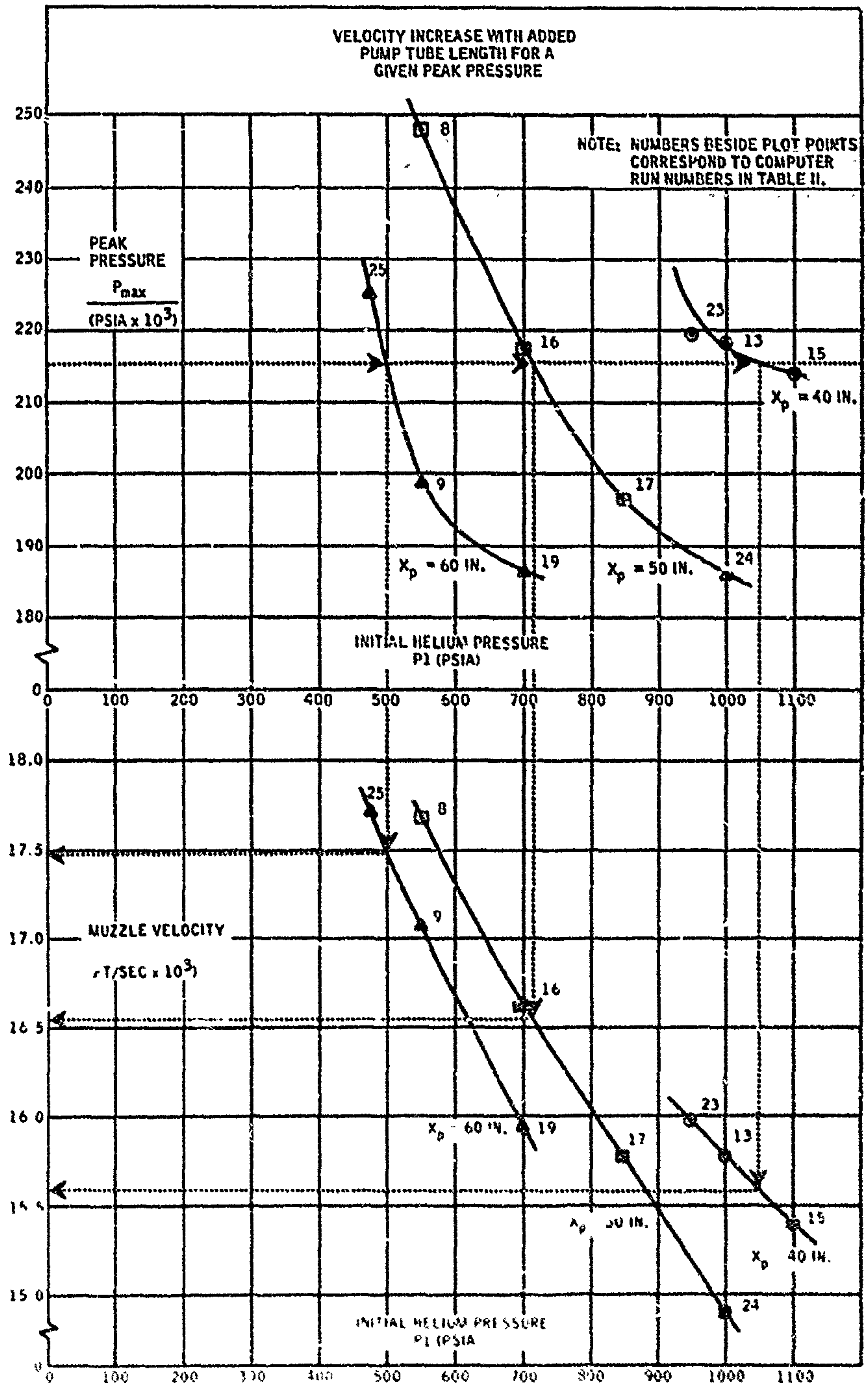


Figure 13. Computer Study: Effect of Pump Tube Length

can be achieved with a heavier piston -- (again, considering only the present launcher configuration and range of parameters). An example of this trend is seen in a comparison of the results of runs 6 and 9 in Table II.

These benefits of increasing pump tube length and piston mass were also limited by practical considerations. Lengthening the pump tube results in increased weapon weight and dimension. Moreover, a longer pump tube makes necessary a somewhat longer charging time, a slightly longer ejection time, and possibly a more damaging carrier impact velocity. (The magnitudes of these effects in relation to added pump tube length have not yet been investigated.) For the present phase of testing, a pump tube length of 50 inches was felt to be a good compromise. In the case of piston mass, it is apparent that a heavier piston results in increased ammunition weight. Also, for a given ejection pressure, the heavier piston requires more time to be ejected. For the current firings, a piston mass of 25-30 grams was chosen; however, this parameter, perhaps more than any other, is open to further consideration in regard to performance optimization. Potential gains in velocity must be weighed against the penalties of increased system weight and more difficult ejection.

Launch tube length was selected by assuming that the friction between the accelerating projectile and the bore walls could be represented by an equivalent "average resistive pressure" of 500 psi. From the computer runs, curves of projectile velocity vs. bore travel were plotted, and the bore length was then chosen as the minimum travel required for the projectile to attain 95% or better of its maximum potential velocity. The resulting barrel length was 35 inches (117 calibers). Beyond this point, velocity gains per unit length were found to be very slight, and did not justify the use of a longer and heavier barrel.

Projectile shot-start pressure was briefly considered in the study. For one case (compare runs 9 and 10 in Table II), decreasing the shot-start pressure from 20,000 psi to 5,000 psi resulted in a slight reduction in muzzle velocity as well as a slight reduction in the muzzle velocity to peak pressure ratio. Increasing the shot-start pressure to 100,000 psi (run 11) raised the peak pressure so greatly, and caused piston bounce-back to occur so early in the launching run, that it was felt useless to consider these higher values further. Values of shot-start pressure between 20,000 psi and 100,000 psi were not considered, since it was evident from an examination of the detailed results that the shock-action characteristic of the launcher caused variations between these limits to have little or no effect on muzzle velocity and peak pressure. (The second shock reflection from the base of the projectile, according to these computer simulations, effected a jump in base pressure from about 14,000 psi to about 80,000 psi.)

Helium was the only light gas considered in this study, since it is always employed in the actual experimental firings rather than hydrogen. This choice is solely for reasons of safety, due to the presence of oxygen in the test environment. In the space environment for which the weapon is intended, there is no reason why hydrogen gas should not be used, thereby resulting in a slightly greater velocity potential. (In addition, it has been reported by several experimenters that erosion of the launch tube bore is found to be less severe when hydrogen, rather than helium, is used.)

This optimization study obviously cannot be regarded as the final word on the selection of parameters for the weapon. The reliability of the computed simulations has not yet been confirmed by firing data or checked in comparison with simulations generated by other computer programs.* In addition, certain of the parameters, such as piston mass and pump tube length, were rather arbitrarily limited by practical considerations which could later be given more or less importance in relation to muzzle velocity. More experimental work is required to establish the magnitudes of these practical limitations before a final selection can be made.

With these reservations in mind, it may be stated that the computer study achieved a great deal. According to these predictions, the new launcher has a velocity potential far in excess of the previous design, with only slightly increased weight and dimension required. Moreover, these higher velocities can be achieved with lower initial helium pressures, which favorably affects the charging phase of the firing cycle.

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*Plans have been made to run a number of "check" cases on computer programs developed at other agencies. The U.S. Naval Research Laboratory (Washington, D.C.) and the U.S. Naval Ordnance Laboratory (Silver Spring, Md.) were approached with this proposal for comparing results. At each of these agencies, personnel contacted were cooperative and interested, and agreed to undertake the work. Unfortunately, delays in the primary computational program and in the experimental program have resulted in a postponement of these back-up studies. It is still planned to perform these additional computations, and a summary of the results will be prepared for future reference.

SECTION IV

WEAPON PERFORMANCE VS INCREASED PROJECTILE MASS

It was attempted to determine experimentally, during this phase of testing, the effect of increased projectile mass upon muzzle velocity and peak pressure. The primary aim of this investigation was to discover the maximum mass which could be fired from the present launcher at a velocity above 10,000 ft/sec without causing excessive pressure to be created in the gun. In addition to the experimental data, a few of the computer simulations were devoted to a consideration of heavier projectiles.

The experimental firings have not so far produced a sufficient amount of valid data to justify a representation of the empirical relationship between projectile mass and velocity. Projectiles of masses varying from 1.27 gm (20 grains) to 3.58 gm (55 grains) were prepared for firing, but only two different weights, 1.27 gm and 2.72 gm, have been fired. Of this data, some of the velocity measurements were invalidated by severe bore damage and consequent retardation of the projectile in the launch tube. From the witness screens, it was also apparent that the projectile usually fragmented in firings with a damaged bore. Only the lightest of the projectiles, 1.27 gm, has been fired with complete success; these light projectiles were made of aluminum and did not produce gouging in the launch tube bore as did the steel projectiles. The itemized pressure and velocity data from these firings is presented in Appendix A.

The best indication to date of the effect of increased projectile mass upon performance has been obtained from the computer study. In runs 16, 20 and 21 (Table II) projectiles of masses 1.0 gm, 2.0 gm and 3.0 gm respectively were programmed, using the same initial conditions for each. Insufficient allowance was made for the increase in peak pressure caused by the heavier projectiles, and the runs exceeded the pressure limit which had been assigned to the computations. In runs 24, 26 and 27, these cases were repeated with the initial helium pressure raised to 1000 psi, and the simulations ran to completion.

The sensitivity of muzzle velocity and peak pressure to variations in projectile mass, as obtained from these computations, is plotted in Figure 14. These curves apply in a strict sense only for the particular combination of gun geometry and initial loading which was selected for the runs. However, this particular configuration is probably not far removed from that of the eventual weapon, and the slopes of these curves are in all likelihood representative of the trends that may be expected for any configuration in this neighborhood of parameter values.

Experimental firings are continuing briefly, and in the few remaining shots an attempt will be made to obtain more actual test data in this area of investigation.

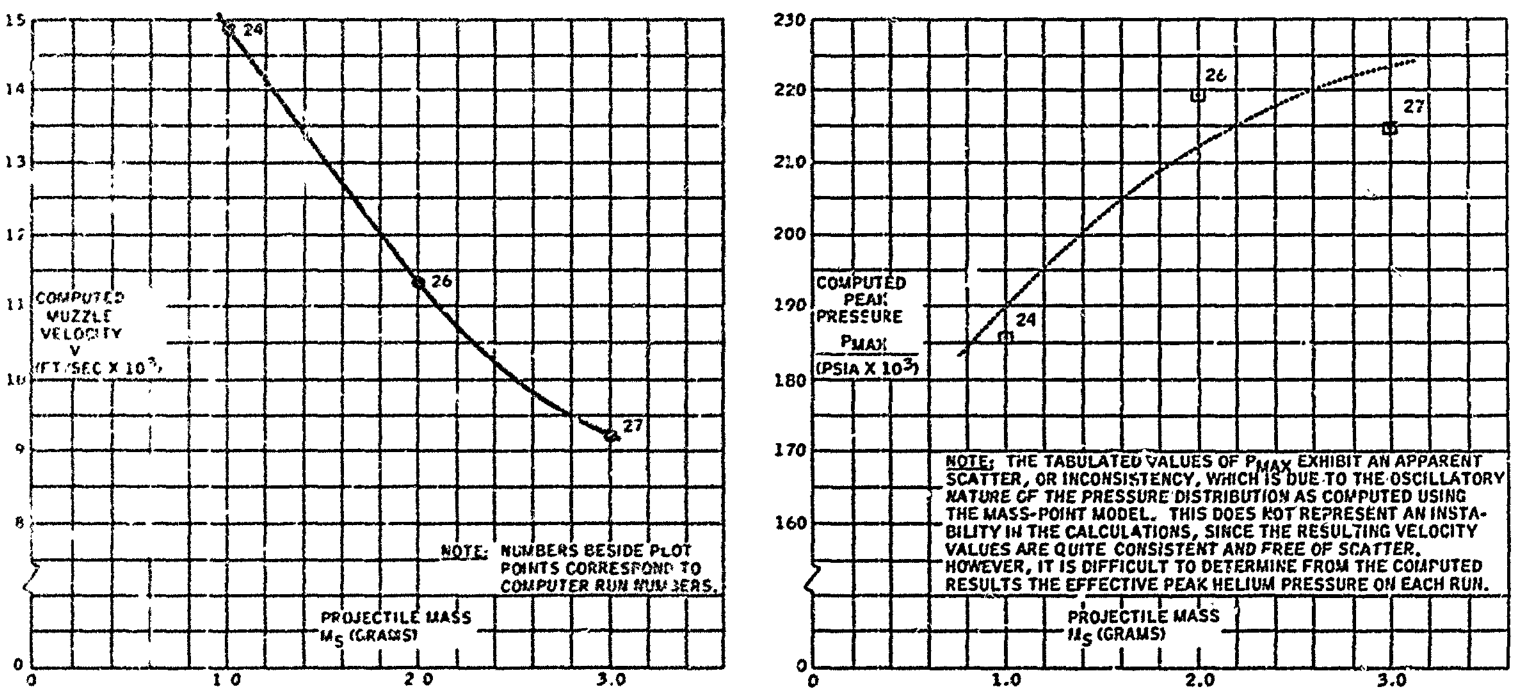

Figure 14. Computed Muzzle Velocity and Computed Peak Pressure Vs Projectile Mass

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SECTION V

PROBLEM AREAS

During the previous phase of the project, several problems were encountered which required solution if a successful weapon was to be developed. The work scope for the present phase was written to include study of these. Solutions have been found in some cases. In others, further knowledge has been gained, but final resolution will require continued and more extensive study.

CARRIER IMPACT

Considerable damage is sustained by the carrier assembly as it 'slams' into firing position during injection. If deceleration due to impact is excessive, the projectile is sheared from its flange by its own inertia. Premature projectile shear aborts the firing cycle and might well result in destruction of the forward breech, for the piston will then be fired into an empty chamber.

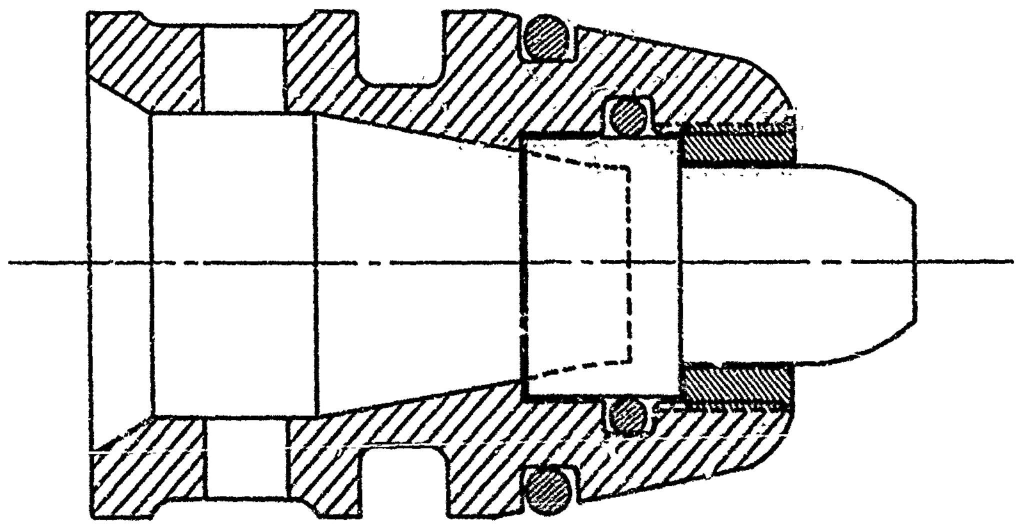
Hence the carrier/projectile design must achieve a balance between two conflicting demands. The projectile-flange unit must be strong enough to sustain the high load of injection impact, and at the same time it must be sufficiently weak to shear at the desired shot-start pressure.

It is desirable, of course, to reduce the impact load on the projectile-flange unit by some means. Lower injection pressures would accomplish this, but initial helium pressures above 500 psi are required for firing with the present configuration. Among the remaining possibilities for preventing or reducing damage due to carrier impact are:

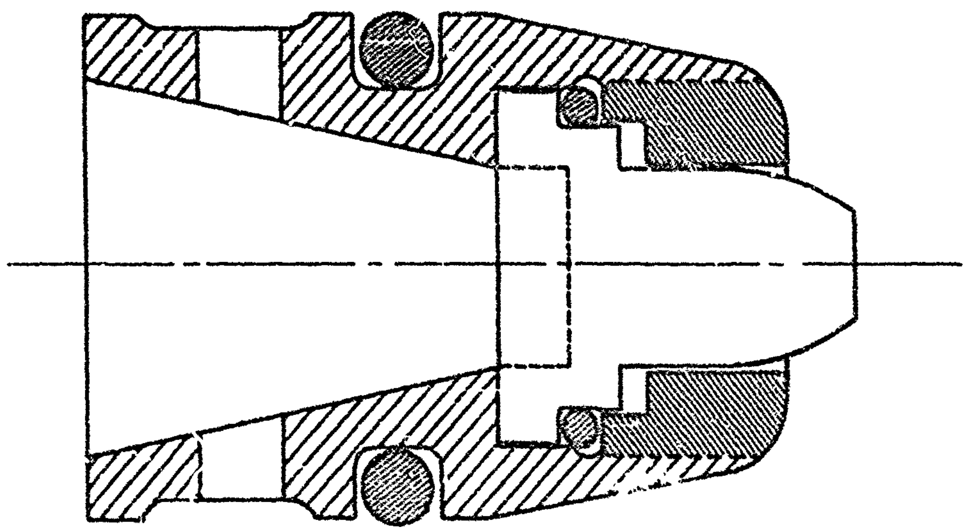
(1) Employ a two-stage charging process. The carrier is driven into firing position with injection gas at low pressure (perhaps 100 psi); as soon as the carrier is seated, full flow rate is permitted, and full charging pressure is rapidly established.

(2) Allow the carrier to crush or deform in a limited, controlled manner, such that the deceleration is "spread out" and the peak deceleration forces are reduced.

(3) Allow some of the injected helium to bleed by the carrier as it drives the carrier down the tube. This gas, whether it were permitted to escape out the muzzle or whether the muzzle were momentarily capped, would cushion carrier impact to some extent. (See Figures 15-a, 16.)



a) Gas Bleed-By



b) Shock-Absorbent Packing

Figure 15. Alternate Carrier/Projectile Designs Considered for Reducing Impact Damage

(4) House the projectile unit in the carrier such that the projectile flange is cushioned against a ring of shock-absorbent packing. (See Figure 15-b.)

Of these schemes, only the last two are now being actively considered. Method (1) has the disadvantage of requiring a longer total charging time. Charging the pump tube presently requires about 200 milliseconds, the longest single delay in the firing cycle. It is desirable to decrease, rather than increase, this time requirement if satisfactory firing rates are to be realized. Method (2) has not been fully investigated, but a few initial tests in the transparent pump tube have indicated that the technique is not sufficiently effective in reducing peak deceleration loads.

Since carrier transit time (i. e. the time required for the carrier to travel the length of the pump tube and seat) is small in comparison with total charging time, Method (3) appears to be a good potential solution. In this method, termed "gas bleed-by", leakage of the injection gas past the carrier is controlled by the dimensional clearance between carrier O. D. and pump tube bore. The volume of gas which bleeds by the carrier during its travel down the pump tube acts as a buffer as the carrier nears the end of its travel. If the muzzle is not momentarily capped, this gas can, of course, escape out the launch tube; but the launch tube bore acts as a second orifice and impedes its escape to some extent.

The gas bleed-by process is a pneumatic-dynamics problem. The diagram in Figure 16 illustrates it in schematic form.

With the diagram as a model, equations can be written which will describe the system. Variables will be pressures P_1 and P_2 and carrier motion. Fixed parameters will be the three effective orifice coefficients, carrier mass, and supply pressure.

Dynamic analysis is practical only after pressures, dimensions and carrier mass have been finally selected. Since they have not been as yet, no analytical work has been attempted. Instead, some rudimentary laboratory tests were carried out to substantiate the concept empirically. Existing carrier/projectile assemblies were driven down the transparent pump tube with and without permitted leakage, and effects were observed. Controlled gas bleed-by was effected by omitting the "O" ring on the carrier O. D. which normally forms a moving seal at the bore walls. A smaller "O" ring was installed on the conical nose to form a seal upon final seating of the carrier. Steel projectiles brazed for shot-start pressures of 60,000 psi were used in the carriers. Projectile weights of 55, 42 and 24 grains were used in the tests.

Results showed gas bleed-by to be effective in delaying the point at which failure occurs. Carriers for which no leakage was permitted failed at much

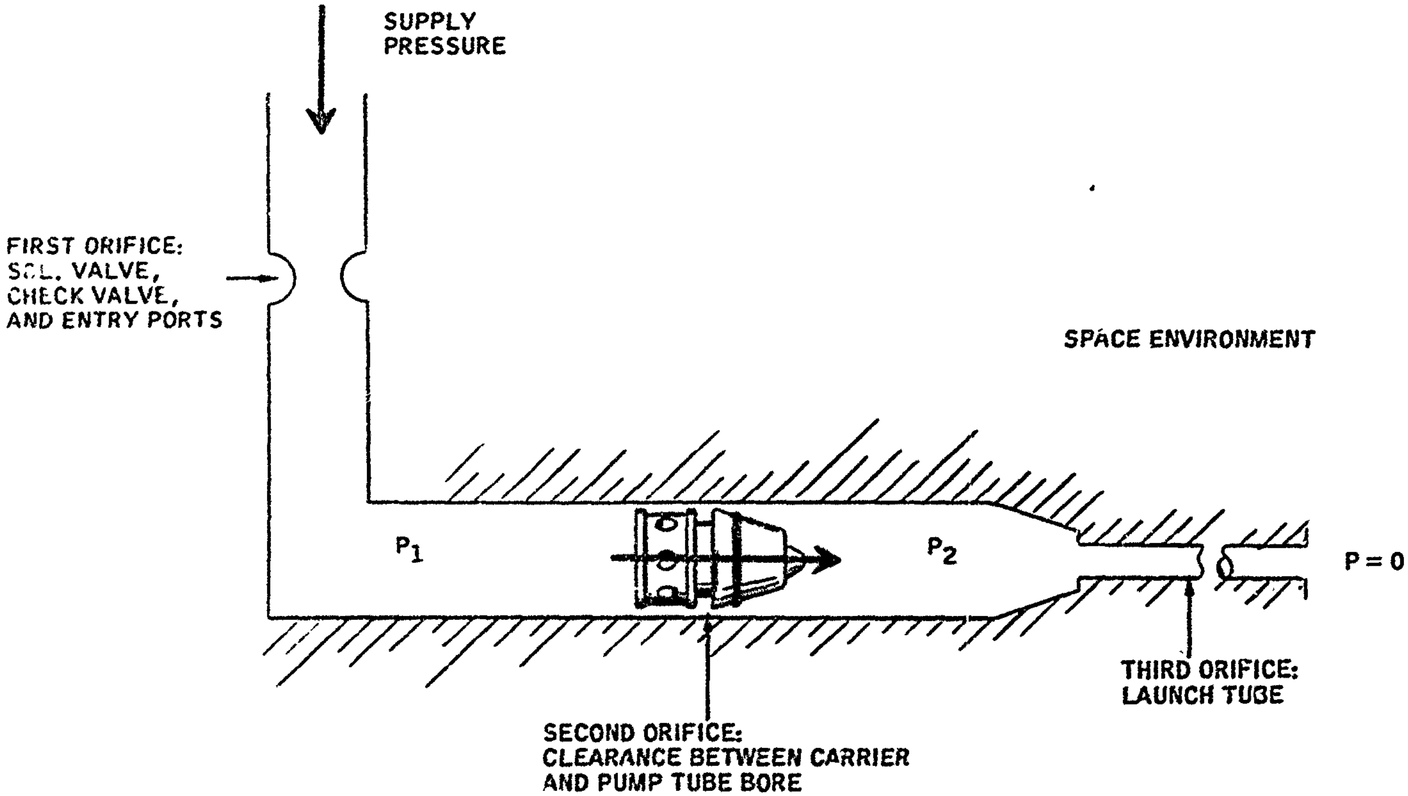


Figure 16. Schematic Representation of Gas Bleed-By

lower injection pressures than carriers with leakage. For example, the heaviest projectile (55 grains) sheared from its sleeve upon impact at only 300 psi charging pressure (i.e. the pressure in the charging reservoir). A somewhat lighter projectile (42 grains) withstood impact at 300 psi, but failed when tested at 500 psi. Employing the gas bleed-by technique, the 55 grain projectile failed at 750 psi; and the lightest projectile tested (24 grains) withstood charging impact at 750 psi. The techrique may provide a solution to the problem of carrier injection damage, and a detailed analysis should be conducted when gun parameters are more definitely established.

ENLARGEMENT OF PUMP TUBE BORE

During the previous phase of testing it had been noted that after only a few firings there existed a measurable increase in the diameter of the pump tube bore at the high-pressure section. The magnitude of this expansion after 15 firings was approximately 0.020 inch. Since the coupling section of the gun is designed to contain a steady pressure of 200,000 psi without permanent yield, it was assumed that the enlargement was due to pressures in excess of this value. Oscilloscope records of the pressures generated by helium compression had indicated that peaks of 300,000 psi and above had occasionally been reached in the firings*. It was therefore concluded that if peak pressures could be kept below the design limit of 200,000 psi, bore enlargement would be prevented, or at least reduced to an insignificant magnitude.

The first five firings of the present test phase gave hope that this conclusion was correct. Peak pressures were kept below 180,000 psi (according to the oscilloscope records) and an enlargement of only 0.006 inch was measured in the region of the pressure port (refer to Figure 8). A second high-pressure section, used for the next eleven firings, also showed an enlargement of only .006 inch. Expansion of the pump tube bore in this region is no longer regarded as a serious problem, in any case. It has been shown that the carrier is able to seal the forward end of the pump tube by means of an O-ring added to its conical face; hence, contact between the bore walls and the O-ring on the carrier O.D. is not necessary for containing the helium charge during injection once the carrier is seated. Expansion of the bore walls would become a serious problem only if the enlargement were so severe that the carrier swelled out into the expansion during firing and could not, therefore, be ejected. It is not known at what extent of enlargement this would begin to occur, but the magnitudes encountered so far (0.006 to 0.020 inch) apparently have not restricted or hampered carrier ejection in any way.

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* Because of the intensity of the pressures and temperatures, and the extremely fast rise and fall of the pressure curve, these measurements are very difficult to make and must be regarded with some uncertainty.

Should the diameter of the bore continue to enlarge during repeated firings, it might become necessary to redesign the coupling section for greater strength. Possible means of achieving this strength are:

a) Pre-stressing the inner layer of the barrel in compression, using the multiple-layer construction often proposed for this section of light gas guns.

b) Starting with the inner diameter slightly undersize at the critical area and using the principle of autofrettage to create a work-hardened bore of the proper diameter with increased resistance to further expansion.

LAUNCH TUBE BORE DAMAGE

It has been mentioned (Section IV) that the experimental velocity data was in some cases invalidated by the effects of bore damage. The damage observed during this phase of testing was nearly identical to that reported during the previous phase. Apparently, it consists of two separate phenomena: a severe but uniform erosion of the bore surface near the entrance (caused by the flow of helium gas at extremely high pressure and temperature), and a more or less random scraping and gouging of the bore surface by the steel projectile along the length of the bore (the precise cause of which is still undetermined).

No attempt was made during the present phase to alleviate the problem of uniform erosion caused by the hot helium gas. This phenomenon is a familiar one in hypervelocity guns, and cannot be prevented entirely, although means of increasing useful bore life have been studied and are applicable to this weapon.[1] Briefly, the wear pattern caused by this erosion may be described as a slight increase in bore diameter at the launch tube entrance, a continuing increase forward of this point, and a gradual return to the original bore diameter.[2] This eroded area extends for a length of about two inches down the bore from the entrance, the point of maximum erosion occuring between 1/8 inch and 1/4 inch from the entrance. The rate of wear in the present barrels is suggested by a measured increase of 0.050 inch (17%) at the point of maximum erosion after only five rounds had been fired. However, a portion of this measured increase may be attributed to a gradual yielding of the bore due to the extremely high pressures near the entrance. (The launch tubes were of a hardness RC-32/37, compared with the coupling section hardness of RC-50/55.)

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[1] See, for example, Reference 2

[2] It had previously been thought that the launch tube entrance became "constricted", but this was found to be an erroneous assumption.

Several aspects of the present design had been aimed at correcting or alleviating the second type of bore damage. This severe gouging was thought to be caused either by balloting of the steel projectile in the launch tube, or by shock wave impingement on the base of the projectile during its travel down the tube. Since the projectiles were machined to an extremely close fit with the bore (.0007 inch average clearance), it did not seem possible that balloting should occur unless the projectile was made undersized by being forced through the "constricted" launch tube entrance. With this possibility in mind, the new projectile was allowed to protrude partially from the nose of the carrier such that upon carrier seating the projectile would be positioned part way into the launch tube. In addition to this change, the projectile was given a rounded nose (to prevent the chance of scraping the bore with a sharply cornered leading edge), was restrained by a brazed fit rather than by an integral shear flange (to insure a clean projectile O.D. of exactly known dimension) and was hollowed out at the base (to provide the effect of an obturation cup for better sealing).

None of these changes were effective in reducing the gouged condition of the bore when firing steel projectiles. However, during this test phase aluminum projectiles were tried for the first time, and it was discovered that after seven firings (starting with a new barrel) the bore showed no observable gouges or indentations. This result was not wholly surprising, since consultation with other agencies early in the program had revealed that bore deformation of this sort had been observed by other experimenters and corrected by adopting plastic sabots or by firing only soft-material projectiles. However, the exact cause and nature of the damage resulting from the use of steel projectiles without sabots remains undetermined. During a study of light gas gun performance for Project Defender, C.D. Porter, of the U.S. Naval Research Laboratory, observed "launch tube enlargement" at certain points along the bore and proposed the following explanation: When the projectile is released, the sudden admission of high pressure gas into the launch tube creates an oscillatory response in the barrel walls. This response consists of a rapid diametral expansion and contraction, such that the bore is first dilated and then contracted relative to its original diameter. During the dilation phase, gas leakage by the projectile occurs, eroding the bore surface; upon contraction, the projectile is actually "squeezed" by the launch tube, causing the observed gouging or "enlargement" of the bore. (A more complete description of the experimental observations and the proposed explanation is contained in Reference 3.) This theory, although tentative, accords with the patterns of the actual damage better than any other explanation so far proposed. It is planned to determine if an oscillatory motion of the barrel walls is, in fact, created by firing, using strain gages attached to the O.D. of the launch tube.

It also remains to be determined if continued firings of aluminum projectiles in the same bore will consistently prevent the formation of the described gouging. In any case, it is already certain that a great improvement is afforded by the use of aluminum as the material contacting the bore. This result suggests the use of projectiles jacketed with a soft metal, if a hard core material is desirable from the standpoint of terminal ballistics.

ACCUMULATION OF COMBUSTION PRODUCTS

In previous tests, residue deposited in the forward breech by firing proved to be troublesome and often hindered successful ejection. Much of the contamination appeared to come from the various piston materials being evaluated, but it was not certain that this was the only source.

Aluminum piston noses have been used in the current series of tests. Accumulation of contaminants has been observed to be much reduced and in fact is not troublesome in single shot firing. Evaluation of the problem under conditions of rapid, repeated firing will not be possible until that stage of development is reached.

Although it is not a combustion product, molten aluminum is suspected of condensing on the walls of the high pressure section. When aluminum projectiles are fired, a similar deposit is observed in the launch tube bore near the entrance.

Whether this metallic deposit will be a problem for repeated firings is not yet known. The aluminum is not thought to come from the projectile itself, but rather from the carrier and from the shear ring which remains after an aluminum projectile shears. This ring shows evidence afterwards of having been partially washed out and may then be redeposited along the bore.

INCONSISTENCY OF MEASURED DATA

This was cited as a problem in the earlier tests. Data in the present tests is satisfactorily reproducible (see Appendix A). The change can probably be attributed in part to the improved installation of the pressure instrumentation (previous velocity data was not as inconsistent as the pressure data) and to the use of a different propellant having better combustion characteristics under these particular firing conditions.

CARRIER ATTACHMENT TO PISTON

No effort was expended in this direction. The carrier design does not yet seem sufficiently permanent to warrant it.

SECTION VI

CONCLUSIONS AND RECOMMENDATIONS

1. It is felt that the breech mechanism design is generally successful and can be adapted to multi-barrel operation. The demonstration that piston and carrier can be ejected through the bolt opening with speed and consistency was an important step in the development.

2. Timing studies of the various segments of the firing cycle indicate that a cycle time of 300 milliseconds is feasible. Pneumatic delays are primarily responsible for the present long cycle time. Quick opening valves and other possible means of reducing the time requirements of the pneumatic processes should be investigated.

3. Velocity measurements of the ejected debris give indications that recoil forces created by firing may be reduced considerably by ejecting straight to the rear. A six-degree of freedom recoil analysis remains to be performed for the case of a multi-barrel rotary weapon.

4. For the present basic weapon size (20mm pump tube diameter) the launcher dimensions and mass ratios have been very nearly optimized, provided that the computer simulations are valid and that the estimates regarding practical limitations are correct. The results of the computor study should be compared with cases run on other programs, and more extensive and reliable firing data should be obtained to provide confirmation or correction of the simulations.

5. The damage caused by charging impact to the carrier/projectile assembly is still a major impasse. An intensive study should be made of this problem to find a positive solution satisfying both the requirement of rapid charging and the requirement that the carrier be capable, after impact, of proper firing and ejection.

6. Slight enlargement of the pump tube bore at the high-pressure section is no longer troublesome, unless repeated fire operation causes continued and excessive enlargement. In that event, the coupling section could be redesigned for greater strength. It is recommended that an integral high-pressure section, with no joint in the critical carrier seat area, be substituted for future firing tests.

7. Launch tube bore damage remains a major problem. The rapid erosive wear at the entrance and the gouging deformation along the bore are conditions incompatible with weapon effectiveness. The use of aluminum as a projectile material has eliminated gouging deformation in the limited number of firings made. The possibility of using steel or other hard metal projectiles with soft metal jackets should be investigated.

8. Combustion residue accumulation in the forward breech has been of less consequence during this phase. However, it was discovered that each firing leaves a small deposit of aluminum on the bore walls surrounding the seated carrier. While not hindering single-shot operation, this metallic deposit might build up during repeated fire to an extent that would compromise performance.

9. It is recommended that, in addition to an intensified investigation of remaining problem areas of single-shot operation, steps be taken toward the construction and preliminary testing of a repeated-fire, multi-barrel launcher. As an initial step, it is recommended that work be started on the design and evaluation of a simple automatic feed system for the multi-barrel weapon.

APPENDIX A

MEASURED PRESSURE AND VELOCITY DATA FROM FIRINGS

Round No.	x_p (in)	p_1 (psi)	m_s (gram)	p_{max} (psi)	V (ft/sec)	Range
1	40	1000	*	145,000	11,000	range atmospheric
2	40	1000	2.72	140,000	8,400	range atmospheric
3	40	1000	*	140,000	10,100	range atmospheric
4	40	910	2.72	155,000	8,400	range atmospheric
5	40	990	2.72	155,000	8,500	range atmospheric
6	50	790	1.27	145,000	---	range atmospheric
7	50	600	1.27	160,000	11,700	range atmospheric
8	50	800	1.27	130,000	10,800	range atmospheric
9	50	800	1.27	140,000	11,300	range atmospheric
10	50	800	1.27	155,000	11,000	range atmospheric
11	50	800	1.27	125,000	11,050	range evacuated
12	50	800	1.27	170,000	11,200	range evacuated
13	50	800	1.27	145,000	11,050	range evacuated
14	50	800	1.27	150,000	---	range evacuated
15	50	800	*	170,000	9,560	range evacuated
16	50	800	*	165,000	9,530	range evacuated

*Projectile sheared improperly, actual mass launched is not known.

Definition of Symbols

x_p = length of pump section

p_1 = initial helium pressure

m_s = mass of projectile

p_{max} = maximum helium pressure reached in firing

V = muzzle velocity measured by coil and/or grids

Gun Data

Piston material:	Lexan base aluminum nose section
Piston mass:	27.9 grams
Propellant:	DuPont IMR 4198
Propellant mass:	360 grains

Gun Data (Continued)

Projectile material:	Steel (2.72 gram model)
	Aluminum (1.27 gram model)
Pump tube diameter:	0.786/0.789 inch (20mm nominal)
Launch tube diameter:	0.297/0.298 inch (0.30 cal. nominal)

Remarks

1. Gas leakage at high-pressure section occurred on Rds. 1-3.

2. Increasing bore damage was observed on Rds. 1-5. Projectile fractured in the launch tube on Rds 3-5.

3. New launch tube was installed prior to Rd. 6. All subsequent firings were with aluminum projectiles, and no further bore gouging occurred.

4. Expended piston was ejected on all firings. Expended carrier remained lodged in the high-pressure section on Rds. 1-7 due to problems associated with sealing. With proper sealing techniques established, complete pneumatic ejection was achieved regularly.

LIST OF REFERENCES

1. Proceedings of the Sixth Symposium on Hypervelocity Impact, Vol. I, "Experimental and Theoretical Studies on the Interior Ballistics of Light Gas Guns", Paul G. Baer and Horace C. Smith, August 1963

2. Hypervelocity Guns and the Control of Gun Erosion, Vol. I, Office of Scientific Research and Development, National Defense Research Committee, 1946

3. Hypervelocity Capability and Impact Research, ARPA Order 70, C.D. Porter, U.S. Naval Research Laboratory, NRL Memorandum Report 1348, July 1962

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3. REPORT TITLE
AUTOMATIC LIGHT GAS GUN DEVELOPMENT

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Technical Report for period ending December 1964.

5. AUTHOR(S) (Last name, first name, initial)

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
December 1964	56	3

8a. CONTRACT OR GRANT NO. AF08(635)-4097	9a. ORIGINATOR'S REPORT NUMBER(S) ATL-TR-65-10
b. PROJECT NO. 9850	
c. Task No. 985001	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
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13. ABSTRACT

(C) Work has been continued toward the development of an automatic hypervelocity weapon based on the principles and techniques of the laboratory light gas gun. With the basic feasibility of the firing scheme established by the preceding work phase, effort was aimed at advancing the implementation of the concept. Attention was devoted to those aspects of single-shot operation which required improvement or more thorough investigation before a launcher capable of rapid repeated fire could be constructed. Among the areas of consideration were firing cycle time studies, breech mechanism design, revision of launcher dimensions for improved velocity capability, and studies of problem areas encountered in the previous work. In most respects, good progress was made. Some significant advances toward automatic repeated fire were achieved. However, design ideas and implementation schemes are presently far in the lead of proven firing capabilities. Some of the difficulties encountered in single-shot operation have not yet been eliminated, and these problem areas will require continued study and successful resolution before repeated-fire operation can be attempted.

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