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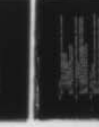
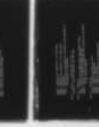
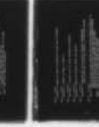
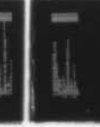
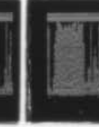
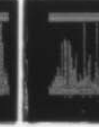
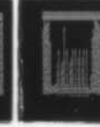
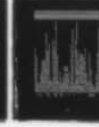
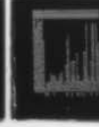
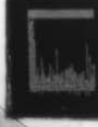
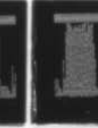
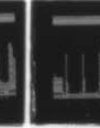
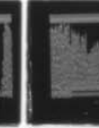
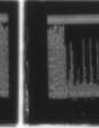
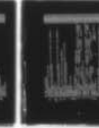
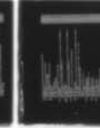
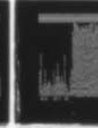
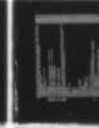
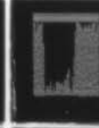
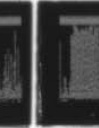
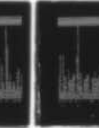
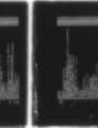
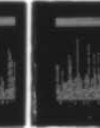
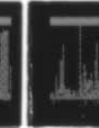
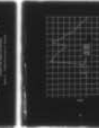
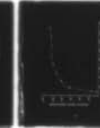
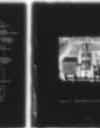
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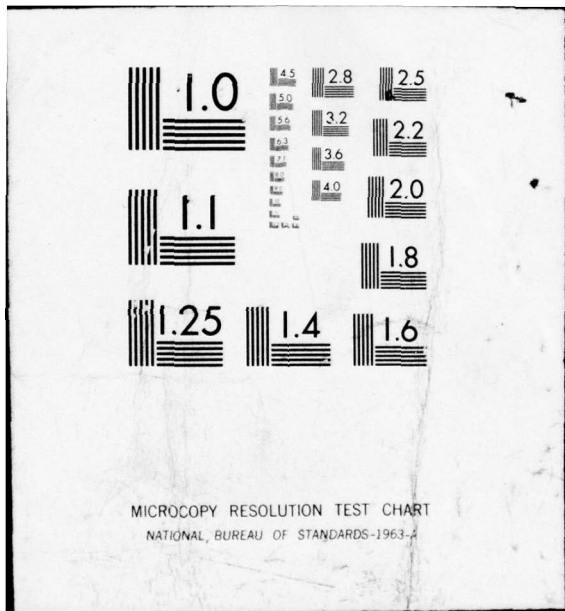
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THESIS

APPLICATION OF HOLOGRAPHIC INTERFEROMETRY
TO THE INTERIOR BALLISTIC FLOW FIELD IN
THE BARREL OF A TWENTY MILLIMETER CANNON

by

Richard Lewis Montgomery

September 1976

Thesis Advisor:

D. J. Collins

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**Application of Holographic Interferometry
to the Interior Ballistic Flow Field in
the Barrel of a Twenty Millimeter Cannon**

by

**Richard Lewis Montgomery
Lieutenant, United States Navy
B.S.E.E., University of Miami, 1966**

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the
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September 1976**

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ABSTRACT

The technique of holographic interferometry was applied to the study of gas core characteristics in the barrel of a 20mm cannon. Using standard hydrodynamic equations theoretical predictions were calculated. Holographic interferograms were made of the associated flow field near the projectile during firing. Reconstruction of the wavefront provided the necessary means of comparing experimental results with the theoretical values obtained.

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LIST OF SYMBOLS

<u>SYMBOL</u>	<u>DEFINITION</u>
A	Cross-section area
C	Constant specifying thickness of shock region
E	Specific internal energy
j	Mass point number
M	Mass
P	Pressure
q	Artificial viscosity
t	Time
u	Velocity
V	Specific Volume
X	Eulerian Position
ρ	Density

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I. INTRODUCTION

For many years the field of theoretical interior ballistics was almost entirely confined to a single problem: given the characteristics of shot, charge, and gun, to calculate the muzzle velocity and peak pressure. (Ref. 1)

With the discovery of the laser and its application to holography, more interesting information can be obtained. It is possible to make a hologram of the projectile and its flow field, then reconstruct the image with exact detail.

Having a thorough knowledge of the physical characteristics of the internal gas flow field is essential in ballistic design. Although thermochemical constants for the products of combustion during actual gun firing are not well known, it is assumed that the gas and the solid grains move together as a homogeneous mixture. If this is true, then the conclusions of the Lagrange hypothesis are applicable to the interior ballistics of a gun.

The motion of the projectile creates a system of rarefaction waves in the breech, with relaxation occurring through the mechanisms of stress transfer in the bed and in the propellant gas. The dual wave system will accelerate the gas and the particles in the direction of the projectile

motion at the expense of stored internal energy. The more volatile gas will follow the projectile more readily than the particles. With progressive motion of the projectile, the initial unsteady flow may be expected to damp out and, as the motion evolves, to assume the quasi-equilibrium character of the Lagrange solution. This is a flow in which the mixture has uniform density, a linear velocity distribution and a quadratic pressure distribution. Eventually, the propellant is consumed entirely. Subsequent motion involves only the propulsion of the projectile by the reservoir of energetic gas. (Ref. 2)

It is the purpose of this investigation to utilize laser techniques and observe this flow field responsible for propelling the projectile as it transits through the barrel of a gun.

II. HOLOGRAPHIC INTERFEROMETRY

Holography is a process which is similar to photography in certain respects, but is nonetheless fundamentally different. Photography provides a method of recording the two-dimensional irradiance distribution of an image. Generally speaking each "scene" consists of a large number of reflecting or radiating points of light. The waves from each of these elementary points all contribute to a complete wave which we call the "object wave." This complex wave is transformed by the optical lens in such a way that it forms an image of the radiating object. It is this image which is recorded on the photographic emulsion.

Holography is quite different. With holography one actually records the object wave itself. This wave is recorded in such a way that subsequent illumination of the record serves to reconstruct the original object wave even in the absence of the object. A visual observation of this reconstructed wavefront then yields a view of the object or scene which is practically indiscernible from the original.

The method of recording the object wave is as follows. One starts with a single monochromatic beam of light which

has originated from a very small source. The requirement of coherence means that the light should be capable of displaying interference effects that are stable in time. This single beam of light is then split into two components, one of which is directed toward the object or scene; the other is directed to a suitable recording medium. The component beam that is directed to the object is scattered, or diffracted, by that object. This scattered wave constitutes the object wave, which now is directed to the recording medium. The wave that proceeds directly to the recording medium is the reference wave. Since the object and reference waves are mutually coherent, they will form a stable interference pattern when they meet on the recording medium. The detailed permanent record of this interference pattern on the recording medium is called the "hologram." This method is illustrated in Figure 1. When the hologram is illuminated with a beam of light which is similar to the original reference wave used to record the hologram, light will be transmitted only through the clear areas, resulting in a complex transmitted wave. Because of the recorded interference fringes, this wave conveniently divides into three separate components, one of which exactly duplicates the original object wave. By viewing

this reconstructed wavefront, one sees an exact replica of the original object. Three-dimensional images of opaque objects may be reconstructed and photographed from different viewing angles using a single hologram.

The above description of holography can be represented mathematically as follows:

$$\text{Let } \bar{E} = \bar{O} + \bar{R} \quad 2.1$$

Where O represents the object or scene beam

R represents the reference beam

$$\text{Then } E^2 = O^2 + R^2 + 2\langle \bar{O} \cdot \bar{R} \rangle \quad 2.2$$

Taking the time average:

$$\langle \bar{E}^2 \rangle = I = I_O + I_R + 2\langle \bar{O} \cdot \bar{R} \rangle \quad 2.3$$

The term $2\langle \bar{O} \cdot \bar{R} \rangle$ in equation 2.3 is the interference term. Without interference the intensity of the two beams are merely additive. With the utilization of monochromatic light derived from a single ideal source, interference is always possible.

Uncorrelated light beams, as from two different light sources, are uncorrelated and are called incoherent. Coherent radiation produces interference effects. The superposition of incoherent radiation yields the addition of the intensities of the object and reference beams.

The interference term contains both amplitude and phase information. Consider two waves such that:

$$\bar{O} \cdot \bar{R} = \frac{1}{2}(\bar{O}e^{-i\omega t} + \bar{O}^*e^{i\omega t}) (\bar{R}e^{-i\omega t} + \bar{R}^*e^{i\omega t}) \quad 2.4$$

Then

$$\bar{O} \cdot \bar{R} = \frac{1}{2} \left\{ \bar{O} \cdot \bar{R} e^{-2i\omega t} + \bar{O}^* \bar{R}^* e^{2i\omega t} + \bar{O} \cdot \bar{R}^* + \bar{O}^* \cdot \bar{R} \right\} \quad 2.5$$

$$2 \langle \bar{O} \cdot \bar{R} \rangle = \frac{1}{2} (\bar{O} \cdot \bar{R}^* + \bar{O}^* \cdot \bar{R}) \quad 2.6$$

If $O_1 = O_1 e^{ig_1}$ etc. and $R_1 = r_1 e^{ih_1}$

$$\begin{aligned} 2 \langle \bar{O}_1 \cdot \bar{R}_2 \rangle &= O_1 r_1 \cos(g_1 - h_1) + O_2 r_2 \cos(g_2 - h_2) \\ &+ O_3 r_3 \cos(g_3 - h_3) \end{aligned} \quad 2.7$$

Thus the interference term contains both amplitude and phase information. From equation 2.6 it is evident that interference occurs only when light beams of the same polarity interact with one another.

The complete interference equation is:

$$I = \langle \bar{E}^2 \rangle + I_R + I_O + R \cdot O^* + O \cdot R^* \quad 2.8$$

where $\langle R \cdot R^* \rangle = I_R$

and $\langle O \cdot O^* \rangle = I_O$

The reconstruction process can also be described with equation 2.8. The amplitude transmittance of the hologram

is assumed to be proportional to the intensity

$$t(x) + KI \quad 2.9$$

On reconstruction with the reference beam R, the following is obtained:

$$R \cdot KI = R(I_R + I_O) + R \cdot R \cdot O^* + R \cdot R^* \cdot O \quad 2.10$$

The last term in equation 2.10 is the reconstructed object beam.

A primary consideration in the technique of holographic interferometry of flow fields is the source of coherent light. The Q-switched ruby laser has proved to be an excellent light source for these applications. It provides the high power necessary to expose the plate in a time frame suitable for freezing the motion of the flow field.

The wavelength of this laser is $6943 \overset{\circ}{\text{A}}$, which is compatible with AGFA-GEVAERT 10E75 holographic film plates. (Ref. 3)

III. EXPERIMENTAL LAYOUT

A. GENERAL PHYSICAL ARRANGEMENT

The experiment was conducted at the Naval Postgraduate School Rocket Laboratory. The laboratory contained four test cells measuring 12' X 17' with reinforced concrete walls 12" thick. A control room with observation windows was located directly behind the test cells.

The 20mm cannon was mounted horizontally on a rocket test stand. Two steel mounts were used to secure the barrel in place at a height of 6.5 inches from barrel center line to the top of the test stand.

Two large wooden tables were constructed and placed parallel to and on either side of the test stand. The tables provided a platform for the optical equipment necessary to obtain holograms. The tables were rigidly fastened together; however, they were completely isolated from the test stand to ensure stability during cannon operation. Furthermore, plywood boxes were constructed to fit over the tables and completely house the optical equipment. The plywood boxes not only acted as protection for the equipment but also acted as a light shield for the

holographic process. The tops of the plywood boxes were hinged in order to allow easy access to the optical equipment.

The muzzle of the cannon faced a bullet trap located 13 feet outside the test cell. The bullet trap contained an 18" X 18" X 1½" armored plate, tilted 45° from the path of the projectile, and a sand trap measuring 5' X 5' X 2½'.

Upon bullet impact, the plate shattered the projectile and deflected the fragments into the sandtrap. In order to provide additional safety, the entire sandtrap was housed inside a steel turret for a 5" gun mount measuring approximately 15' X 20' X 10'.

An electrical firing mechanism was placed at the breech end of the cannon. The firing sequence was directed from the control room.

A light shield was provided to cover the observation window during placement and removal of the holographic plates.

The ruby laser and its components were fixed in position in a test cell adjacent to the cell housing the 20mm cannon. The purpose of this placement was necessary not only for space consideration but mostly for protection of the instrument. A specially constructed table provided support for the laser rail system. The laser was placed normal to the

wall separating the two cells. (Figure 2) A 2-inch hole was drilled through the concrete wall to allow beam passage. A water source for the laser head and output etalon cooling system was incorporated within the test cell. The laser was equipped with a remote control making it possible to fire either from the test cell or the control room. (See Figure 3)

B. BARREL INSTRUMENTATION

For viewing the projectile inside the cannon a .817" diameter hole was drilled completely through the barrel 4.5" from the muzzle. In order to preserve the integrity of the barrel, projectile and flow field, plexiglass windows were designed to seal the port and provide observation inside the barrel. (See Figure 4)

The windows were milled from optical quality 3/4" plexiglass. Two windows were pressure tested in a simulated barrel to 6000 PSI, thus ensuring strength capabilities necessary to withstand internal pressures present. (See Figure 5)

Figure 6 shows the design consideration met for mounting the windows in the barrel. Figure 7 shows the actual barrel with window and with collar.

Figure 8 shows the collar device used to secure the windows in the barrel.

A Kistler 607A pressure transducer was installed 5.5 inches from the breech end of the barrel. This location was just ahead of the tip of the projectile prior to firing. The signal from the transducer was relayed to a Kistler model 504 universal charge amplifier located in the control room. The signal from the charge amplifier was passed to a Tektronix 549 storage oscilloscope. The oscilloscope allowed the signal to be time delayed by a predetermined amount and then amplified to +30 volts, which in turn was used to trigger the xenon flash tube of the Korad K-1 pulsed ruby laser.

A Kistler 603H pressure transducer was located 2.5 inches aft of the observation ports. The signal from the transducer was relayed to a Kistler model 504A universal charge amplifier located in the control room. The signal from the charge amplifier was passed to a Hewlett Packard Model 214A pulse generator where it could be delayed and amplified. The resulting pulse was used to energize the Pockel cells of the Korad K-1 pulsed ruby laser.

The muzzle velocity was measured by the use of two Oehler Model 55 ballistic velocity screens. The screens

were mounted 4 feet apart and placed 81.25 inches from the muzzle of the cannon. As the projectile passed through each screen a 12-volt pulse with an adjustable 2-8 millisecond pulse length was produced and relayed to an Oehler Model 21 chronograph. The two pulses provided a start and stop for the chronograph. Tables of velocities were provided for known screen separation. (See Figure 9)

C. OPTICAL SYSTEM

Figure 10 shows the optical layout used to accomplish the holography. The Korad K-1 pulsed ruby laser was used for the holography process. By utilizing the laser system in the Q-switch mode of operation, high power single transverse mode output could be obtained. A Pockel cell was used to achieve the Q-spoiling required for peak output power.

When operating the Korad K-1 pulse ruby laser in the tem_{00} mode a peak power of 2.5 megawatts with pulse energy of .050 joules over a pulse width of 20 nanoseconds can be realized. The output beam measured approximately 2mm in diameter at a wavelength of $6943\overset{\circ}{\text{A}}$ with a coherence length that exceeds one meter. Figure 3 shows a photographic view of the laser installation.

The laser beam passes through a 2-inch hole in the concrete wall then through another 2-inch hole in the plywood boxes where it first contacts a narrow-band filter which removes the undesired light from the xenon flash tube. The beam then strikes a 2-inch round beam splitter where it is divided into two wave fronts, a scene beam and a reference beam. The intensity of the reference beam is about twice that of the scene beam.

The scene beam is directed along the centerline of a 2.5 meter optical bench where prior to striking mirror #1 it passes through a collimating lens, double concave lens and another collimating lens.

The lens arrangement was designed to allow the scene beam to be expanded to a diameter compatible with the hole drilled through the barrel of the 20mm cannon.

Mirror #1 directed the beam through the windows in the 20mm cannon and onto mirror #2. In order to accomplish this, 3-inch holes were cut in the plywood boxes to permit the beam to pass, allowing enough tolerance for adjustment to ensure that the beam passed through the windows normal to the cannon's axes. Furthermore, mirror #1 was secured to a gimbal mount which allowed a fine adjustment to be made in the horizontal and vertical axes.

Mirror #2 directed the scene beam down the centerline of a 1.5 meter optical bench where a second narrow-band filter was located to remove the unwanted flash from the cannon blast. The beam then proceeds through an expanding collimating lens to mirror #3 where it is directed to the holographic plate. The location of the expanding collimating lens makes it possible to enlarge the scene beam from test section (window size) diameter to a diameter of approximately 4-inches.

After passing the beam splitter the reference beam proceeded to mirror #4 on a 2.0 meter optical bench. The physical arrangement allowed the reference beam to be adjusted to the same length as the scene beam. Mirror #5 directs the beam through two series of expanding--collimating lenses which enlarged the reference beam to approximately 4-inches in diameter at the holographic plate.

Throughout the entire system the optical benches were bolted to the tables on specially designed cross feet which allowed the system to be leveled by adjustment knobs located at each crossfoot. The alignment procedure was greatly simplified by the use of mirrors which contained screw type adjustments for vernier-scale movement about the horizontal and vertical axes. In addition, all the optical components

could be easily positioned along the optical bench. Figure 11 shows the actual optical layout with one plywood box removed to show the arrangement.

The alignment of the system was accomplished by the use of a coherent radiation 3-milliwatt helium-neon continuous wave laser. This laser was mounted on a stand which was placed perpendicular to the axis of the ruby laser cavity. By firing the ruby laser on an exposed polaroid paper a "spot" could be obtained which was used in the alignment process. By placing a mirror at a 45° angle in the ruby laser cavity, the CW beam could be directed through the cavity and centered on the "spot." This centered beam would then coincide with the ruby laser beam and the optical system could be accurately aligned.

IV. FIRING SEQUENCE

All the electrical equipment was turned on to allow the required warm-up time while the test section and optical system were being prepared and aligned. The barrel test section assembly required particular care when installing the plexiglass windows, to ensure that the faces were parallel to the center line of the cannon and normal to the laser beam's path.

After the system was aligned, all electrical equipment was checked for proper settings and all timers zeroed. The opening into the plywood box containing the holographic plate was covered and the alignment mirror removed. The test cell was closed and a holographic plate was placed in its holder. The test cell door was raised to a level just above the muzzle of the 20mm cannon. At this time the cannon was loaded.

The individual who was loading the cannon and connecting the firing mechanism carried with him a safety key which broke the firing circuit at the control panel to prevent accidental firing prior to his clearing the test area. Following loading, the opening into the plywood box

containing the hologram was uncovered and control was then commenced from the control room. All electrical equipment was scanned and the warning horn sounded to alert personnel of the impending shot. The firing sequence was then initiated. A schematic of this sequence is shown in Figure 12.

The charge switch for the laser capacitor was activated. While the capacitor bank was charging, the safety key was installed in the fire control panel and power supplied to the firing mechanism. When the laser ready light illuminated the firing mechanism, capacitors were charged and the cannon fired. Figure 13 shows a view of the control room and monitoring equipment.

The firing process was observed through the observation window. A light shield was placed against the window after firing to protect the hologram from unwanted illumination.

Actual bullet movement was used to fire the laser. On initial firing, a pulse from the Kistler transducer located at the breech was passed to the Textronix 549 storage oscilloscope, where it was delayed and amplified, then used to trigger the xenon flash tube of the Korad K-1 pulsed ruby laser. Considering that the pumping time for the laser is approximately 1000 microseconds and that

approximately 1500 microseconds are needed for projectile travel to the test area, 500 microseconds was used for the pulse delay.

When the projectile reached the second Kistler transducer another pulse was initiated that was relayed to a Kistler model 504A charge amplifier then to a Hewlett Packard Model 214A pulse generator. The pulse generator provided the voltage necessary to trigger the Pockel cell of the Korad K-1 pulsed ruby laser. This unit allowed for a variable signal delay which was used to adjust the time interval for laser firing. Two Monsanto Model 101B timers were incorporated into the system at various locations to provide checks on intervals of interest. Also a Korad KD energy monitor was employed to check the actual laser firing interval.

After firing, the test cell was closed and the hologram removed for processing. The armor plate was inspected for integrity and repositioned if necessary. The 20mm cannon was unloaded and the windows removed and examined for damage.

V. HOLOGRAPHIC FILM AND PROCESSING TECHNIQUE

The Korad K-1 pulsed ruby laser delivered a beam at a wavelength of $6943\overset{\circ}{\text{A}}$. In order to minimize the effects of extraneous light leakage into the system a photographic emulsion with narrow band sensitivity centered in this region was selected. Agfa-Gevaert 10E75 holographic plates were found to be the most suitable for this purpose. This film has a resolution capability of 2800 lines per mm. For holograms produced with $6943\overset{\circ}{\text{A}}$ light this is nearly the required maximum resolution. Reference 4 gives a spectral sensitivity curve for the emulsion.

Following exposure to the laser light the hologram plate was removed from its holder and placed in a closed container and taken to a dark room for development. The initial processing required a five minute bath in kodak D-19 developer. The entire five minute bath was completed in total darkness. Then the plate was rinsed and placed for five minutes in a standard fixer. After 30 seconds in the fixer it was permissible, although not necessary, to turn on green photographic lights in the dark room. From the fixer the plate was washed in water for five minutes and then allowed to air dry. During the entire development

procedure, when it became necessary to touch the hologram it was handled by the edges in an attempt to keep the hologram clear of unwanted finger markings.

When using the 20-nanosecond ruby pulse, it was not possible to control exposure time. Therefore, to ensure the desired intensity, a combination of suitable neutral density filters were placed in the beam paths.

VI. RECONSTRUCTION

To reconstruct the holograms a 15-milliwatt Spectra Physics continuous wave, helium-neon laser was used for the reconstructing wave. A Spectra Physics collimator was fastened to the laser, causing the beam to be expanded to approximately four inches in diameter. The beam was directed to pass through the hologram as outlined in Part I. The converging real image was then photographed with a single reflex polaroid camera using type 55 positive-negative film. This film has a resolution capability of 150-165 lines per mm negative, 14-17 lines per mm positive, thus providing excellent results. The reconstruction process is illustrated in Figure 14. The negatives were further processed at the Naval Postgraduate School photo lab, from which prints were produced.

VII. COMPUTER PROGRAM FOR PREDICTIONS OF FLOW PARAMETERS

The computer program used to predict the velocity of the projectile, pressure and total energy of the flow field was an adaption of a program developed at the Naval Ordnance Laboratory. The program was originally concerned with the analysis of hypervelocity model launchers (Ref. 5). The method of analysis used was essentially a one-dimensional, Lagrangian scheme where the field was divided into six regions each of which in turn was divided into zones. At the interface of each zone mass points were inserted. Each mass was considered to consist of one-half of the mass of the adjacent zone. The hydrodynamic equations, in finite difference form, were then applied to each mass point during the particular interval of interest. The method employed was the "q" method of Von-Neumann and Richtmyer (Ref. 6 and 7).

The following equations were used for this method:

Isentropic flow energy equation;

$$\frac{\partial E}{\partial t} = -(P+q) \frac{\partial v}{\partial t}$$

Equation of motion;

$$\frac{\partial u}{\partial t} = - \frac{\partial (P+q)}{\partial x} \frac{1}{M} A(x)$$

Equation of state;

$$P = P(E, v)$$

$$M = \int^X (X)A(X) dx$$

$$\text{with } \begin{cases} \frac{C_0^2}{v} \frac{\partial u}{\partial y} & , \frac{\partial u}{\partial y} < 0 \\ 0 & , \frac{\partial u}{\partial y} \geq 0 \end{cases}$$

The artificial viscosity term "q" was added to the pressure term in the energy and motion equations in order to spread variable changes created by the shock over a finite region. This allows the equation variables to be considered continuous across the shock. The constant C_0 permits adjustment of the shock "thickness."

The equations were written in finite difference form with initial values of E_0 , P_0 , and V_0 being provided for each region. In order to maintain stability during the process, a new time increment was calculated for each cycle.

During each cycle the pressure was calculated at each mass point using the equation of state and energy. The differential in pressure between mass points was then applied to the equation of motion to determine the acceleration and velocity of each mass point.

For each region it is necessary to input the initial temperature, pressure, molecular weight and a geometrical description.

The program was written in FORTRAN. A listing of the program and the input is given in Appendix A.

VIII. HOLOGRAPHIC RESULTS

Initially the first few holograms obtained appeared to be in the region several centimeters in front of the projectile. However, when further experimental studies did not give the desired results, an investigation was initiated to examine the laser system. It was then discovered that a short circuit had occurred between the plate and cathode of the large thyratron of the Korad power supply. This short circuit would occur approximately 8 minutes following the application of power. This malfunction caused a firing pulse to be continually delivered to the Pockel cell; thus, nearly two-thirds of the seventy-five test firings resulted in holograms in which the laser had fired from 50 to 200 microseconds early. To further compound the problem the Korad KD energy monitor was not available to confirm actual laser firing.

With the incorporation of the energy monitor into the system, and careful monitoring of the power supply, several good holograms were obtained. Figure 15 shows a series of compression waves approximately 2 cm in front of the projectile. Figure 16 shows these same type of waves

approximately 1 cm in front of the projectile. A traveling bow wave can be seen in Figure 17. It is believed that this wave is approximately 3 mm in front of the projectile.

Due to time consideration allowed for this study, the area just behind the projectile was not captured; however, Figure 18 shows a hologram obtained approximately 30 microseconds following projectile passage through the test area. The effects of powder blast not only etch the plexiglass windows but also leave a carbon deposit over the inner faces, resulting in a clouded view of the test area. Further investigations will determine if this powder blast is directly behind the projectile or if there are several microseconds delay between the gas particles and the projectile.

IX. COMPARISON OF ANALYTICAL AND EXPERIMENTAL RESULTS

Analytical results were obtained previously by Robert G. Bettinger (Reference 8) during his work concerning gas core characteristics in the muzzle environment of the 20mm cannon.

Figures 19 and 20 are outputs obtained by Bettinger. Figure 19 summarizes the major input data and initial conditions required, and demonstrates the output format used for representing these data. As shown in Figure 19, a printout was obtained every 0.2 milliseconds. Figure 20 illustrates the output obtained just as the projectile exits the barrel; at this time a muzzle velocity of 1064 meters per second was obtained.

It must be emphasized that the program (Reference 5) does not take into consideration the effects of frictional forces on the projectile. Therefore, in order to obtain a more realistic solution either the program must be modified or the powder parameters altered to account for this constraint. Figures 19 and 20 resulted from the latter choice.

In order to verify these results it was necessary to analyze the powder used to propel the 20mm projectile.

The type powder used in the 20mm cartridge was WC870 with a charge weight of 590 grains. WC870 is a sphere of .305" average grain diameter, with a specific gravity of 1.56 grams/cc. A representative composite is:

Nitrocellulose (13.15%N)	=	81.49%
Nitroglycerine	=	10.0 %
Dibutylphthalate	=	5.5 %
Diphenylamine	=	1.0 %
CaCO ₃	=	0.1 %
AsH	=	0.5 %
Graphite	=	0.15%
Na ₂ SO ₄	=	0.16%
K ₂ SO ₄	=	0.75%
SNO ₂	=	0.75%
Ethyl Acetate	=	0.10%
H ₂ O	=	0.80%

The percentages are given of the dry weight, so that the sum of the ingredients up to the last two constituents is 100%.

The average thermochemical properties of this composition are (by Hirschfelder's approximation, reference 1) as follows:

T ₀	=	2856°K
n	=	0.04218 grams/mol
γ	=	1.2394
F	=	335068 ft-lbs/md
b	=	0.943 cc/gram

The molecular weight of the constituents can be found directly except for nitrocellulose. The nitrocellulose in propellant compositions varies in its nitrogen content. The cellulose molecule is a large one but, for present

purposes, it can be written $C_6H_7O_2(OH)_3$. On nitration, X(OH) groups are replaced by (ONO_2) groups, the value of X depending on the nitrogen content. The resulting compound is $C_6H_7O_2(OH)_{3-X}(ONO_2)_X$. The molecular weight is easily found to be $(162.14 + 45X)$ and, if Y is the percentage nitrogen content, $Y = \frac{1400.8X}{162.14 + 45X}$. This gives

$X = \frac{162.14Y}{1400.8 - 45Y}$. Thus for a given nitrogen content Y and X

can be calculated and the atomic composition found from:

$$C = \frac{6}{162.14 + 45X} \quad H = \frac{10 - X}{162.14 + 45X} \quad N = \frac{Y}{1400.8} \quad O = \frac{5 + 2X}{162.14 + 45X}$$

The heats of formation of the solid propellant can be calculated as outlined in Reference 10.

Inputting the exact values into the computer program resulted in a value of approximately 1463 M/sec. Assuming a projectile drag coefficient of 0.28 (Reference 9), this gives a muzzle velocity of 1036 meters per second which is in excellent agreement with Bettinger's theoretical results.

Furthermore, the maximum possible muzzle velocity (Reference 1) may be calculated from the following:

$$V_m = \frac{2}{\gamma - 1} (RT_0)^{\frac{1}{2}}$$

Using this equation a value of 1097 meters per second is

obtained. The projectile velocity was measured during each firing, and a range of 1020 to 1060 meters per second was obtained.

These values are in excellent agreement with the computer program.

X. SUMMARY AND RECOMMENDATIONS

A considerable amount of difficulty was experienced while attempting to capture the projectile in the test area. Considering the velocity and length of the projectile, passage through the test area occurs within approximately 80 microseconds. Furthermore, considering just the base of the projectile, a time interval of approximately 20 microseconds would result in complete passage of the base of the projectile through the test area. Thus, timing of the laser firing with projectile firing is indeed quite critical.

Referring to Figure 21, it can be seen that the velocity of the projectile approaches a constant value at a distance of approximately 90 cm from the breech of the barrel. It was this fact that prompted the barrel modification to incorporate the pressure transducer near the test area as outlined in Part III Section B. By controlling the firing of the Pockel cell with this transducer, more consistent results were expected.

Theoretically, if the pressure transducer responded instantaneously to the passage of the gas ring of the projectile, the signal produced could be used to pulse the

Pockel cell of the laser just as the nose of the projectile entered the test area.

Unfortunately, 0.5 volts was required to trigger the Hewlett Packard Model 214A pulse generator, while the Monsanto timers responded immediately to projectile passage. Referring to the pressure trace obtained from the pressure transducer (Figure 22), approximately 100 microseconds could pass before the required 0.5 volts was obtained.

In an attempt to confirm the actual passage of the projectile through the test area the pressure transducer was replaced by a temporary contact switch. This switch could only be triggered by actual contact with the gas ring of the projectile. The test confirmed the correct timing of the projectile, agreeing with the results obtained with the pressure transducer as far as the Monsanto timers were concerned.

Due to the fact that most pulse generators require at least 0.5 volts input as a trigger and that the pressure transducer used takes anywhere from 0-100 microseconds to reach 0.5 volts, it is felt that a more positive device must be used to sense the actual position of the projectile. This could be accomplished with a contact switch designed specifically for this purpose.

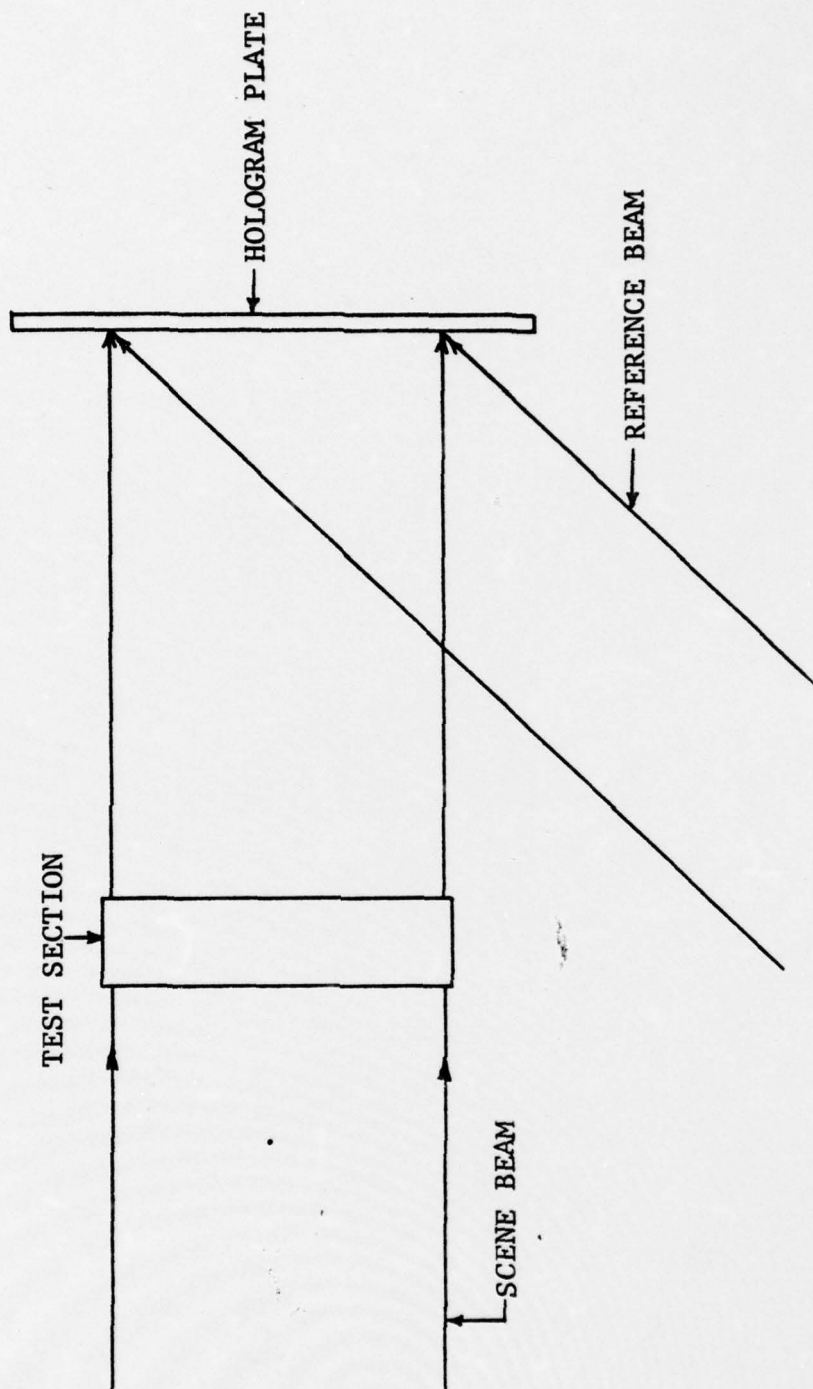
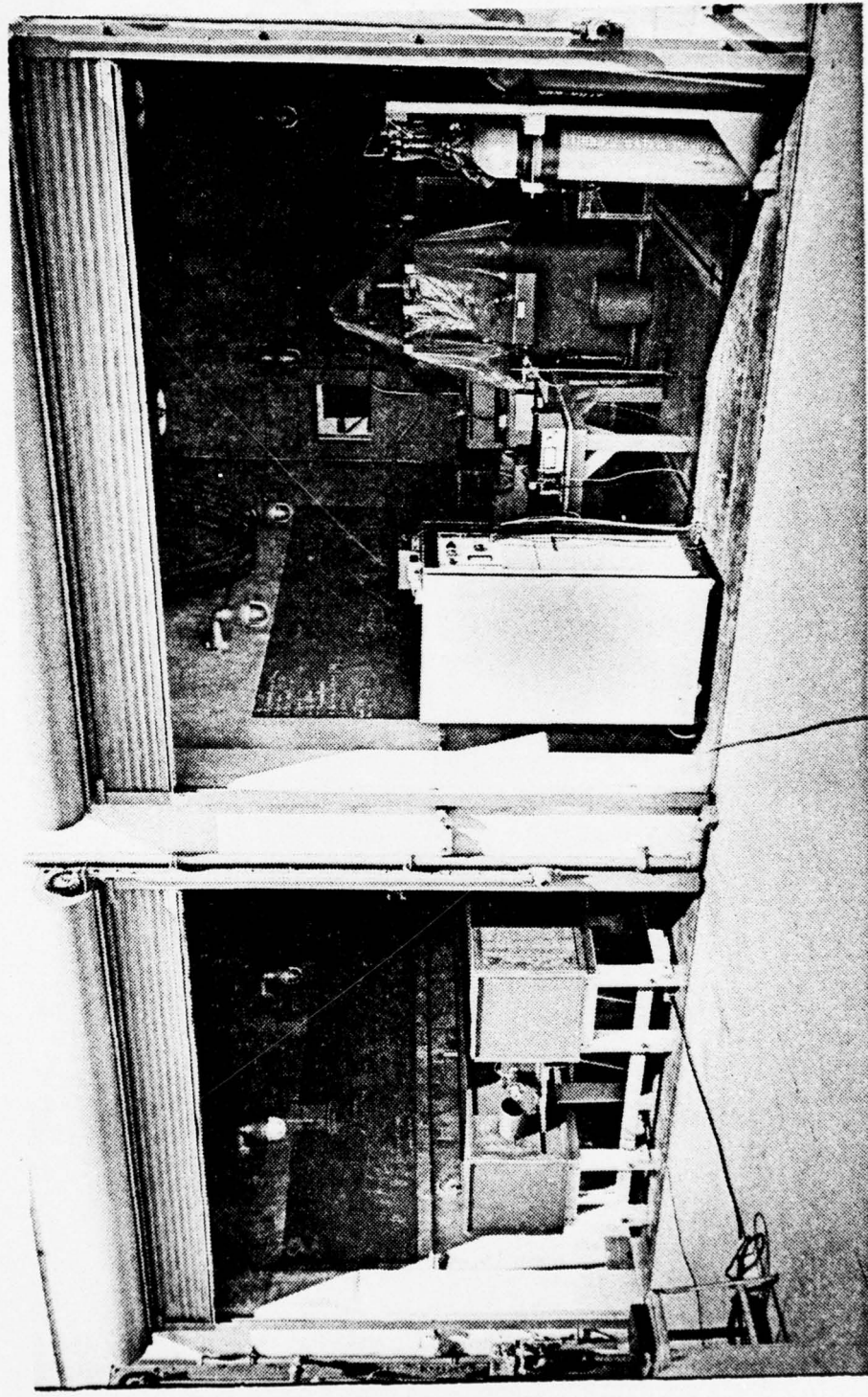


Figure 1. Direct Illumination Method of Obtaining a Hologram



Laser Installation

Cannon and Optics Cell

Figure 2

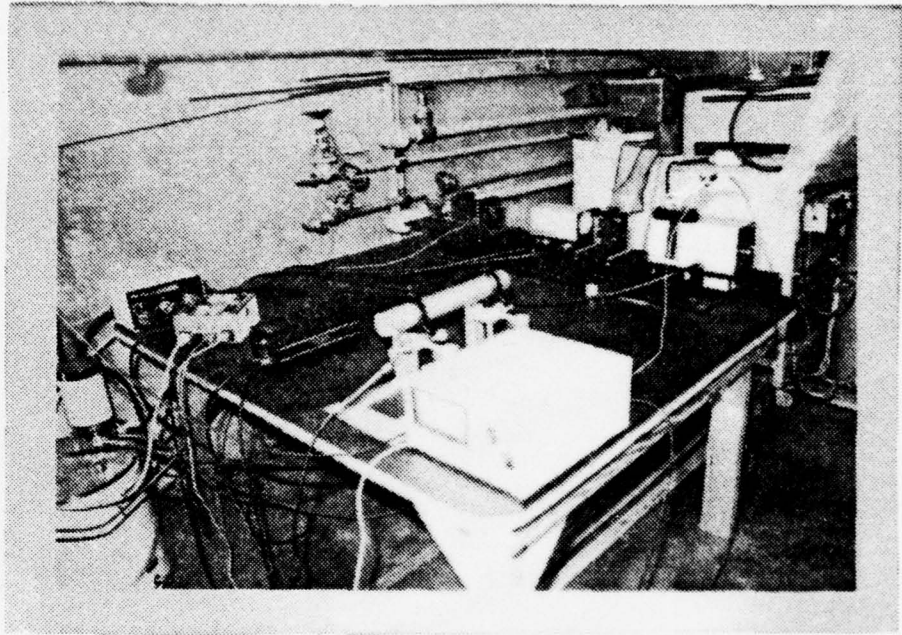


Figure 3. Laser Setup

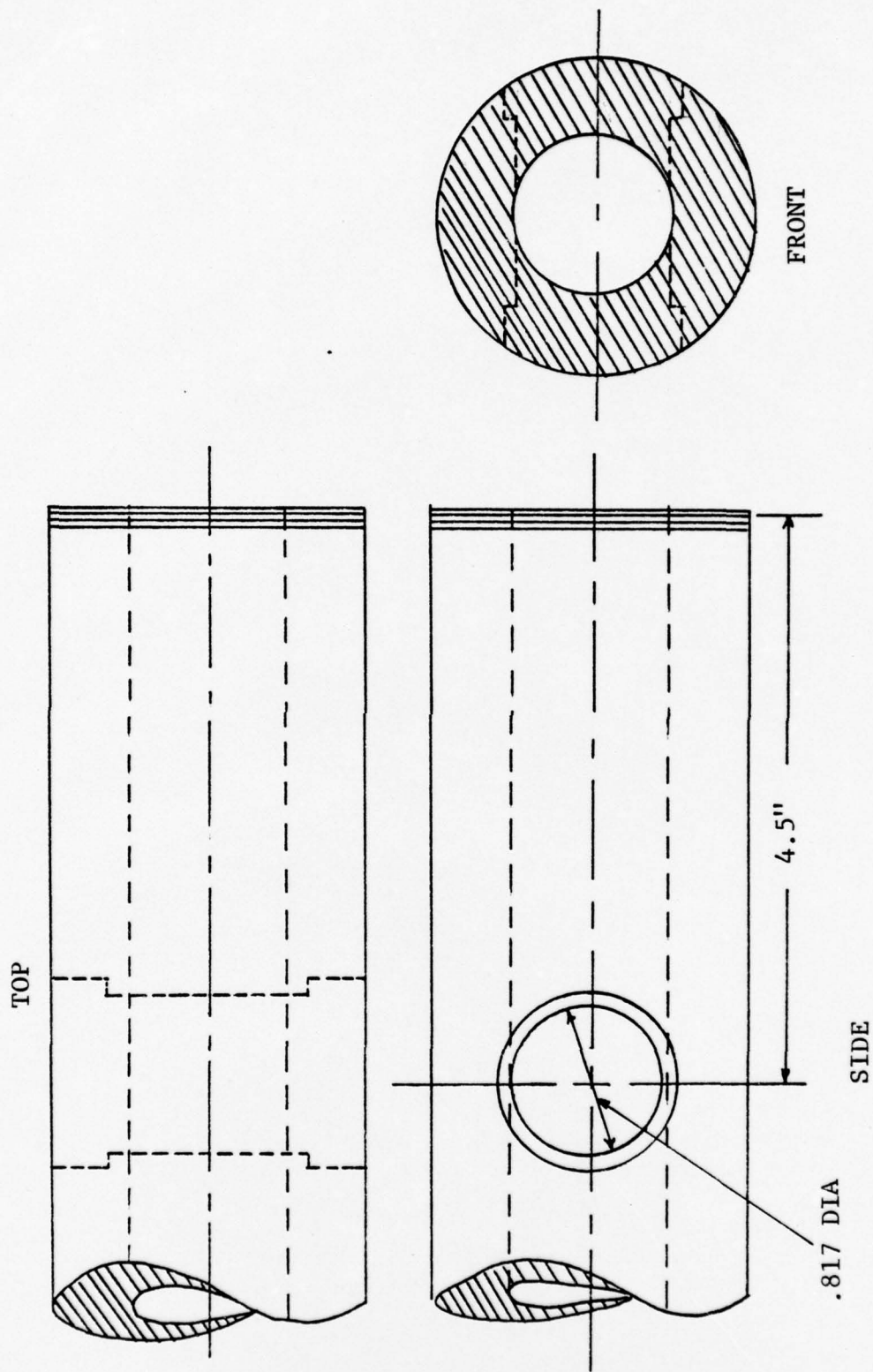
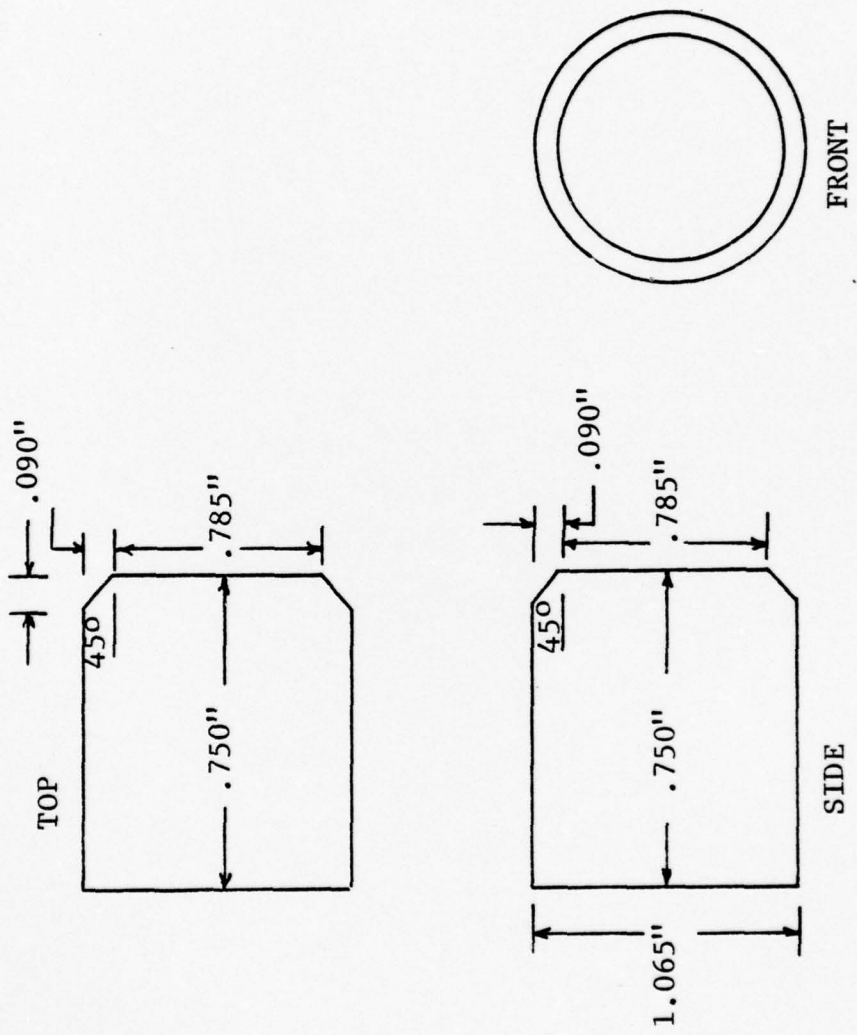


Figure 4. Barrel Design



NOTE: Windows to be seated with #118 O-ring

Figure 5. Plexiglass Windows

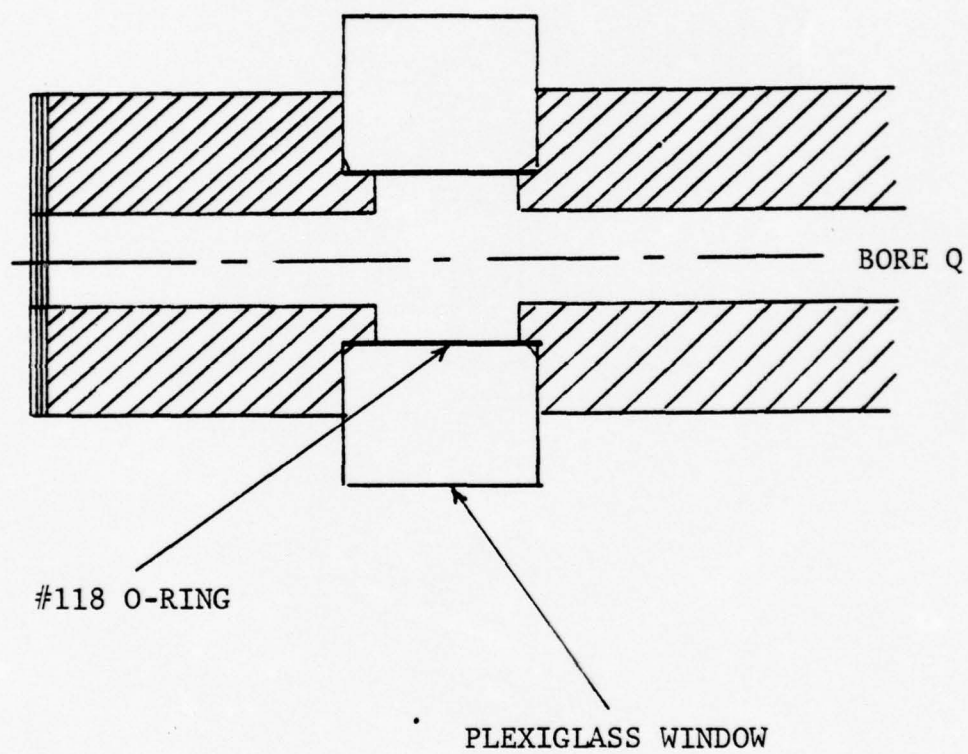


Figure 6.
Top Cutaway View of Barrel with
Plexiglass Window Installation

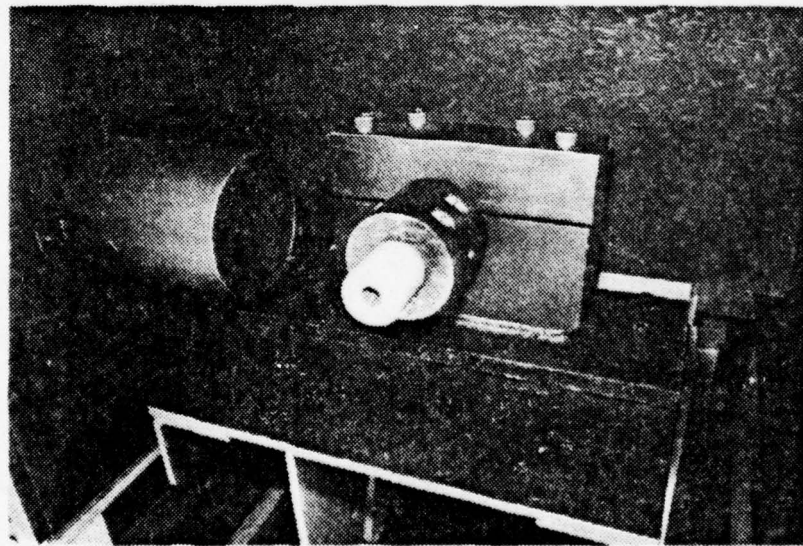
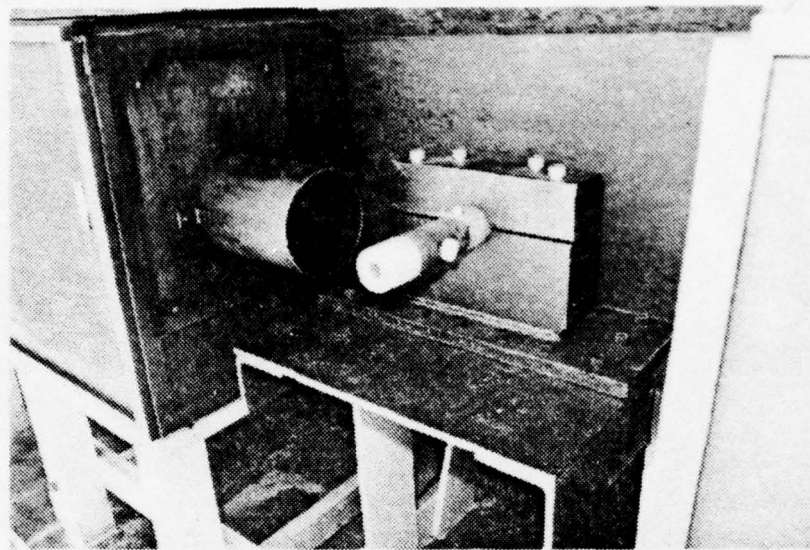


Figure 7. Barrel with Windows and with Collar

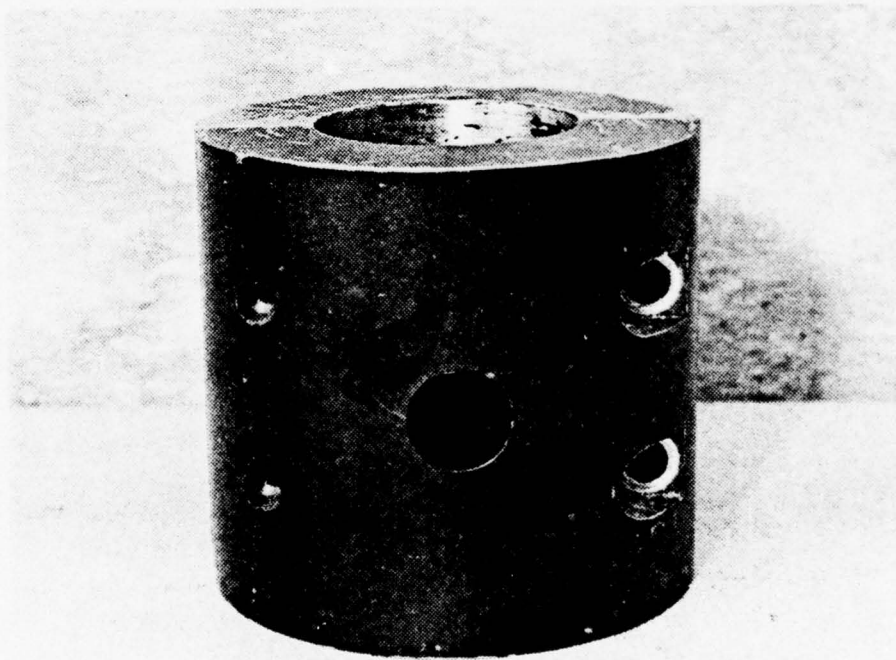
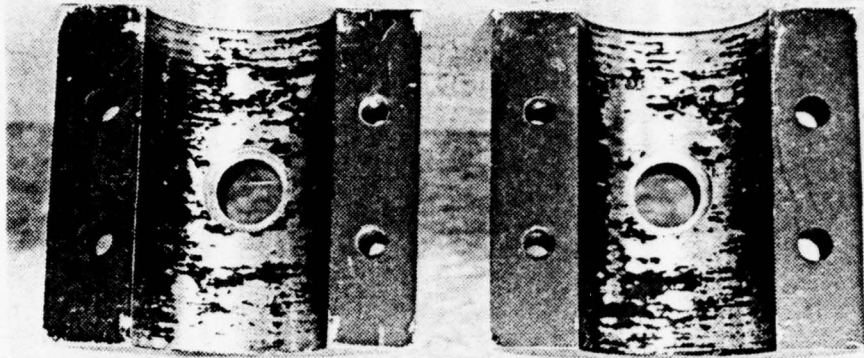


Figure 8. Collar Device

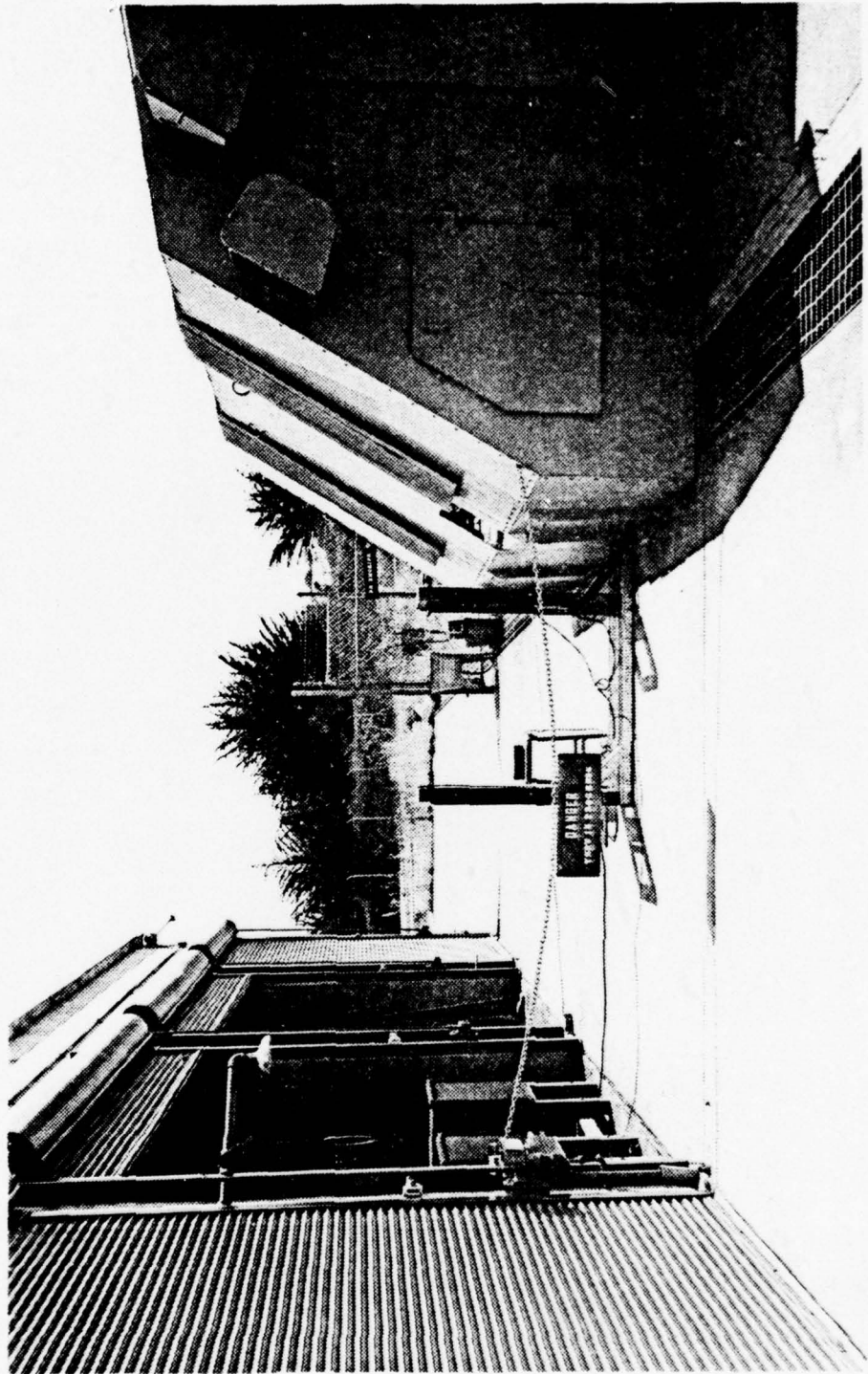


Figure 9. Projectile Path and Turret with Velocity Screen in Place

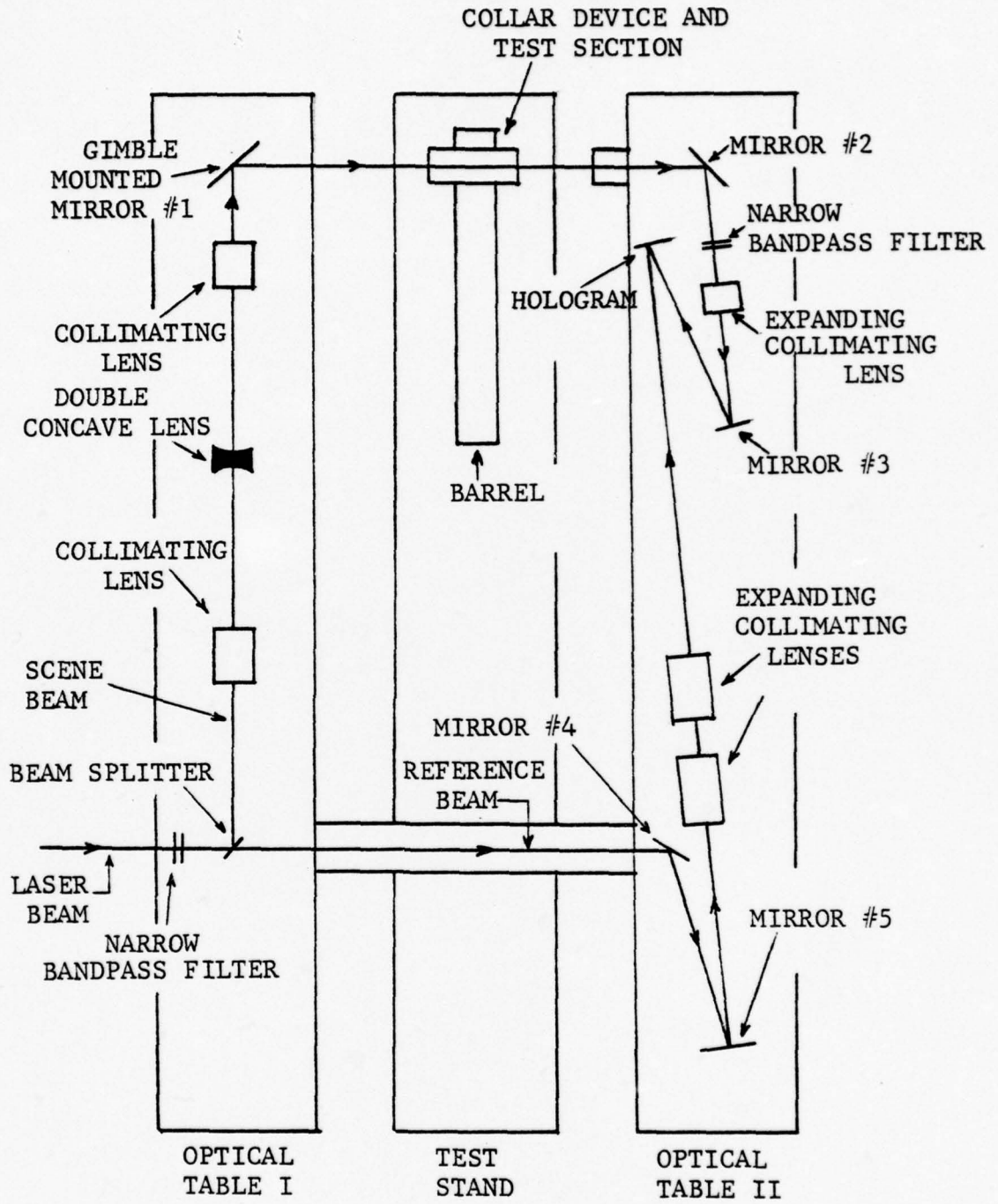


Figure 10. Optical Arrangement

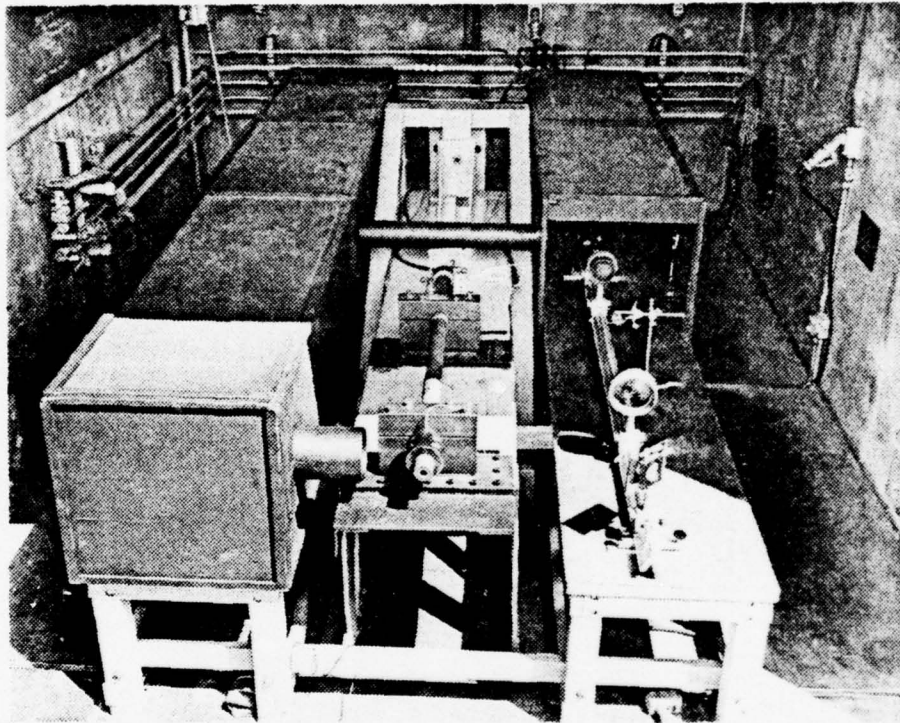


Figure 11. 20mm Cannon with Optical Platform

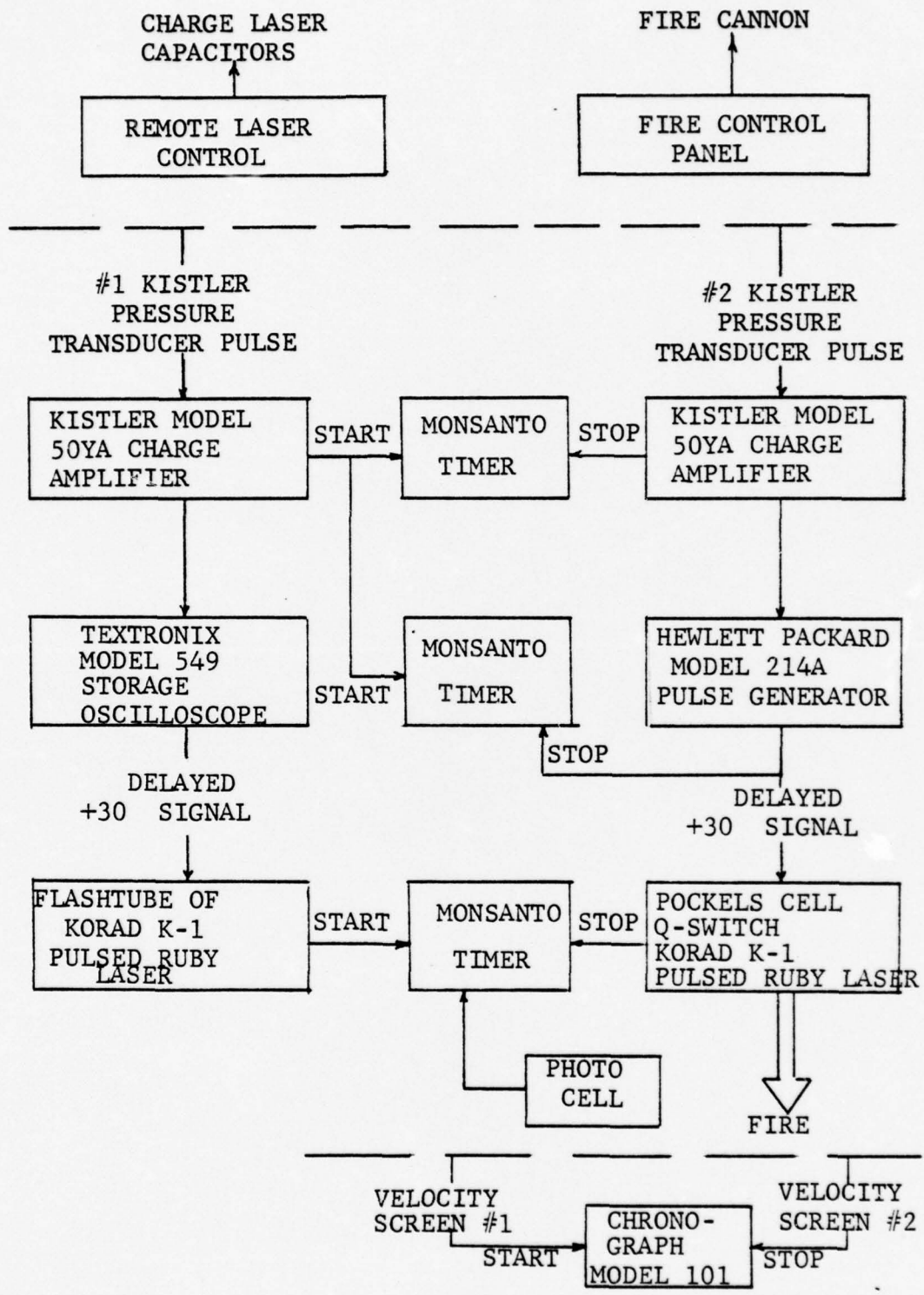


Figure 12. Firing Sequence

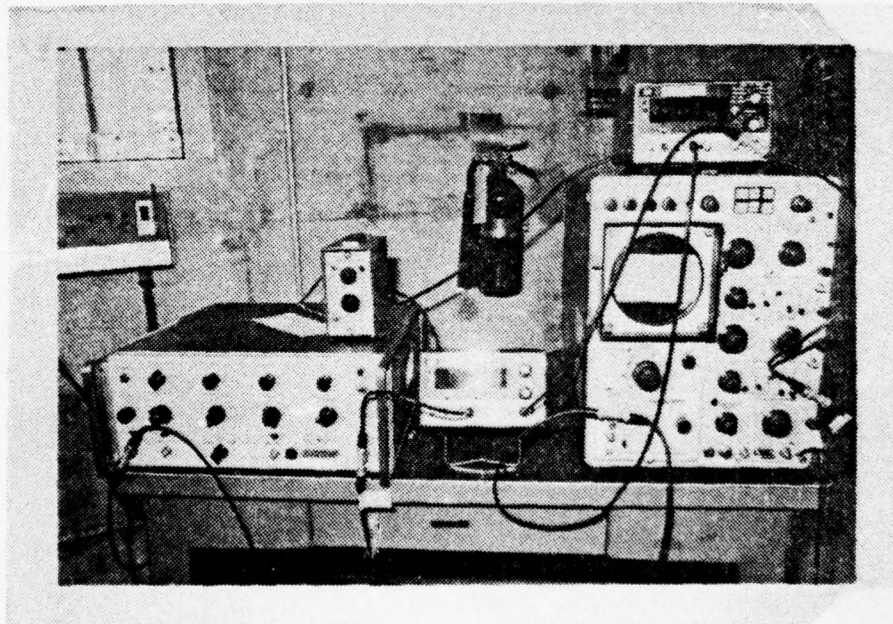
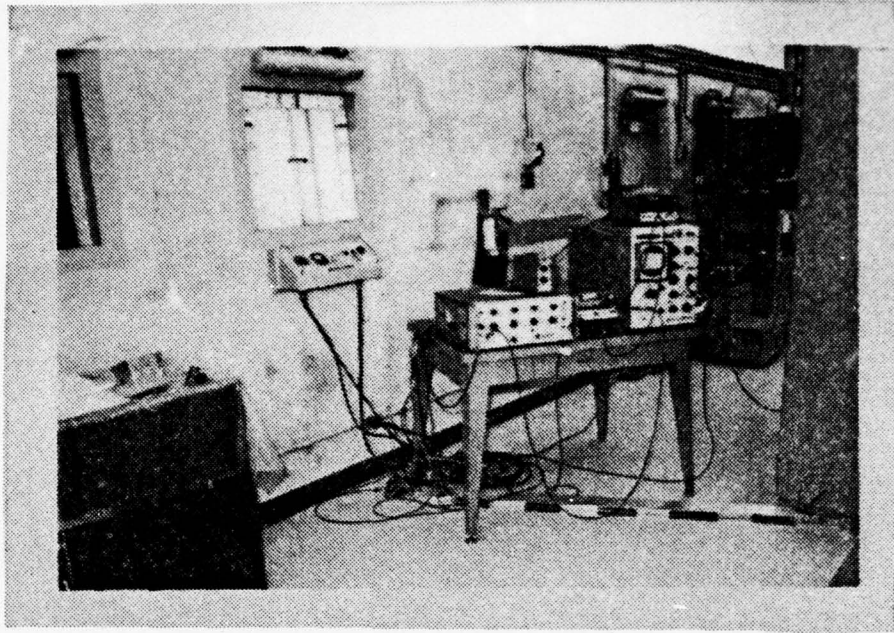


Figure 13. Control Room and Monitoring Equipment

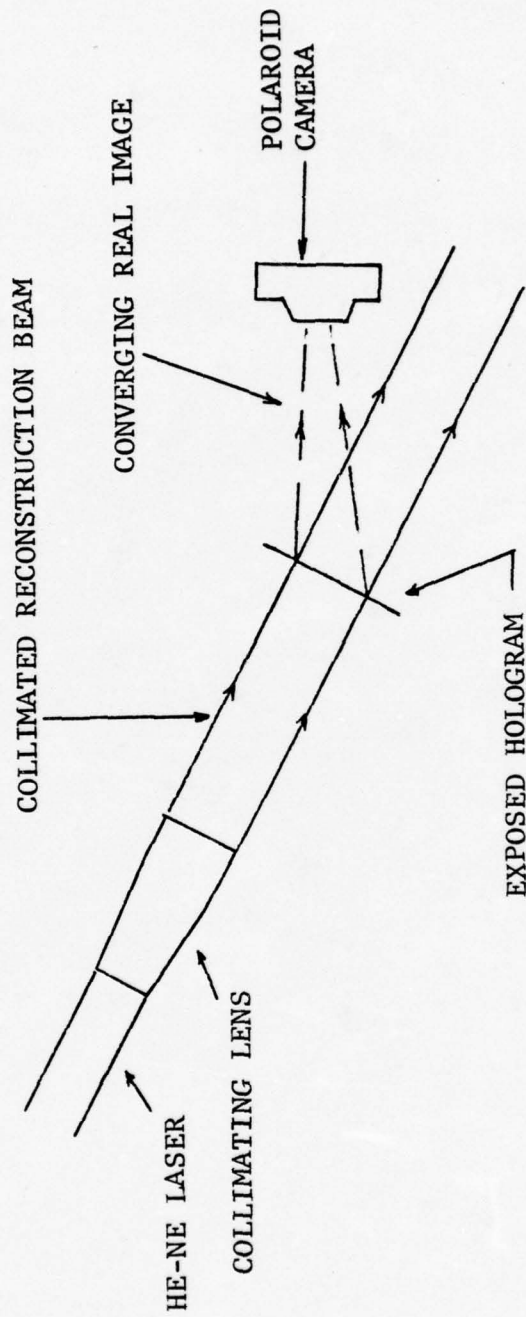


Figure 14. Reconstruction

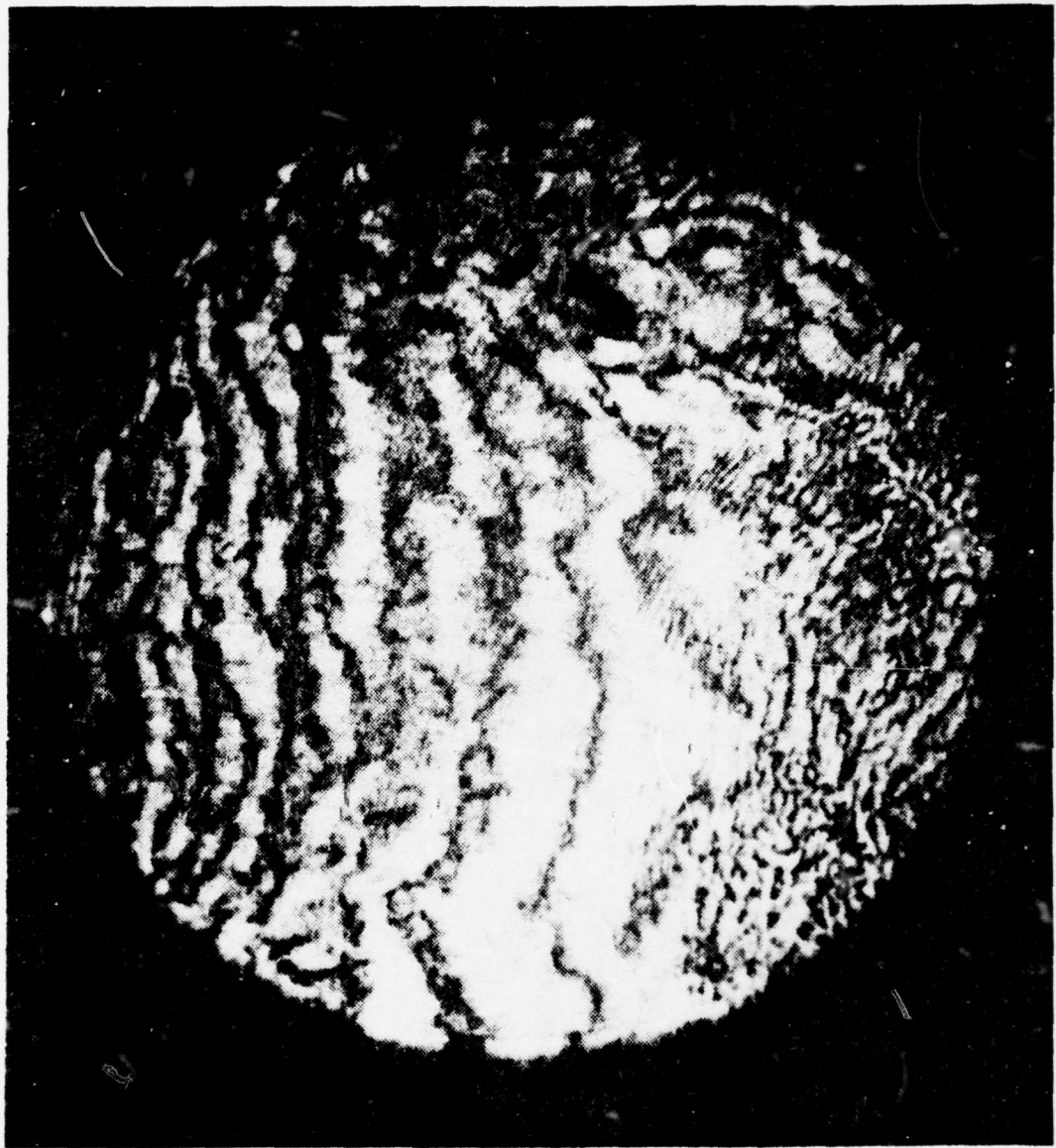


Figure 15. Compression Waves



Figure 16. Compression Waves



Figure 17. Bow Wave



Figure 18. Hologram Showing Carbon Deposits

GUN BARREL PROJECT

Dimensions: 6 Regions, 6 Zones

<u>Regions</u>	<u>Zones</u>	<u>Length (cm)</u>	<u>Area (cmsq)</u>	<u>Volume (cc)</u>
1	1	1.47	2.95	4.35
2	1	1.47	2.95	4.35
3	1	1.47	2.95	4.35
4	1	1.47	2.95	4.35
5	1	1.47	2.95	4.35
6	1	5.40	2.95	15.93

INITIAL CONDITIONS

Powder Conditions: Grams Powder = 38.23
TBURND = 1.00 Millisec

Materials:

<u>Region</u>	<u>NEQST</u>	<u>Pressure (psi)</u>	<u>Temp. (Deg. K)</u>	<u>Molec. Wt. (gm/mole)</u>
1	2	14.7	300.0	125.00
2	2	14.7	300.0	125.00
3	2	14.7	300.0	125.00
4	2	14.7	300.0	125.00
5	2	14.7	300.0	125.00
6	3	3.0	300.0	55.85

Print out every 0.20 millisec up to 10.00 millisec

Print out every 0.050 millisec up to break

Print out every 0.200 millisec up to launch

Mass of Projectile = 90.0 gm

Break Valve Strength = 690.0 Bars

Number of Pressure Points: 1

Location of Pressure Points: 14.0 cm

Figure 19. Computer Output Format

GUN BARREL PROJECT

Cycle 290	T(Millisec)	1.88443E00		
	DT(Millisec)	2.18257E-02		
j	X(CM)	VELOCITY (CM/MS)	PRESSURE (BARS)	
1	0.0	0.0	1.01381E 03	
2	1.46490E 02	1.01004E 02	8.52849E 02	
3	1.47602E 02	1.03653E 02	7.78181E 02	
4	1.48734E 02	1.06449E 02	8.85098E 02	
5	1.49668E 02	1.07232E 02	1.05442E 03	
6	1.50551E 02	1.06399E 02	3.98267E 02	

Figure 20. Computer Output Format

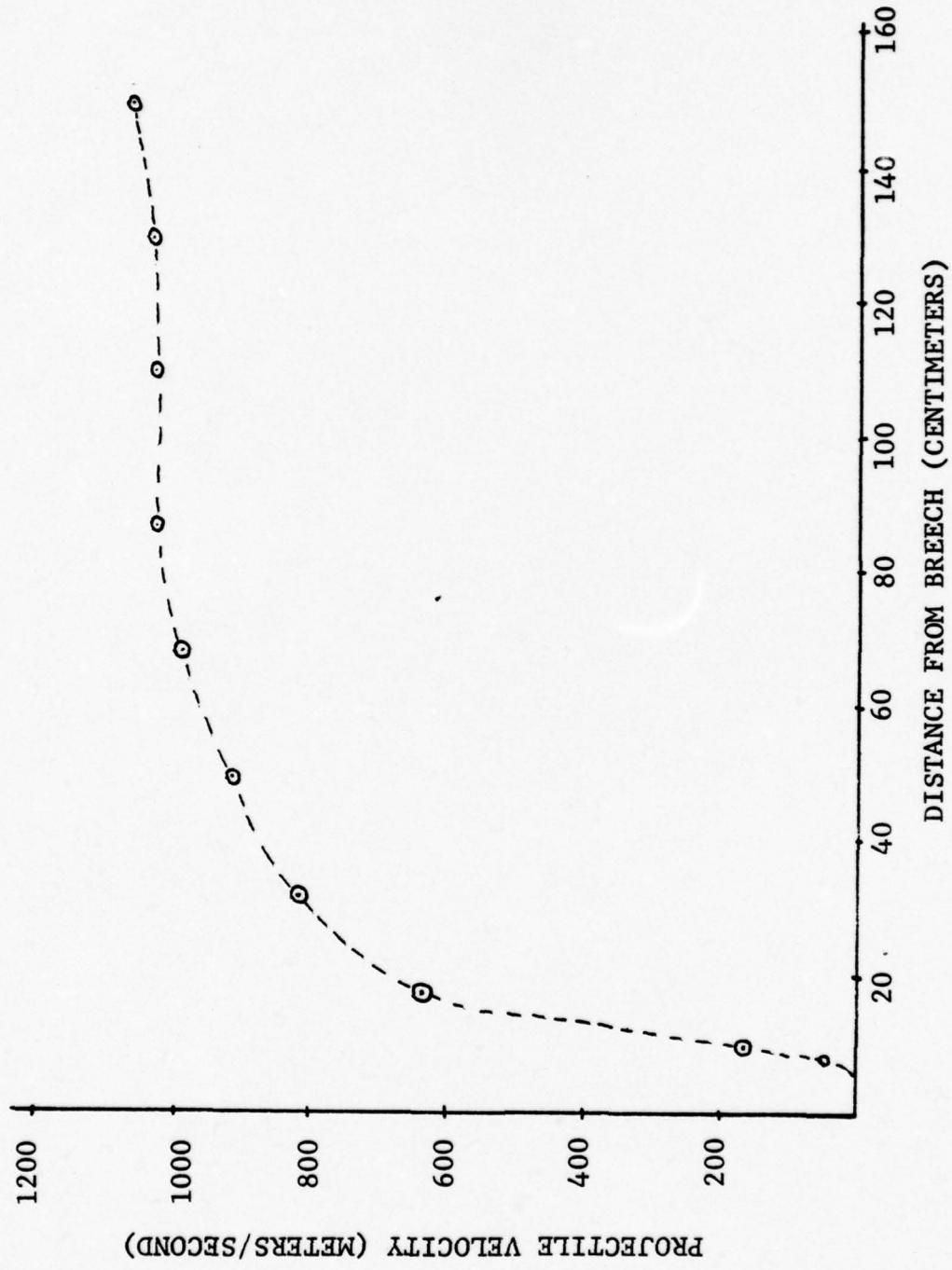


Figure 21. Projectile Velocity vs. Position

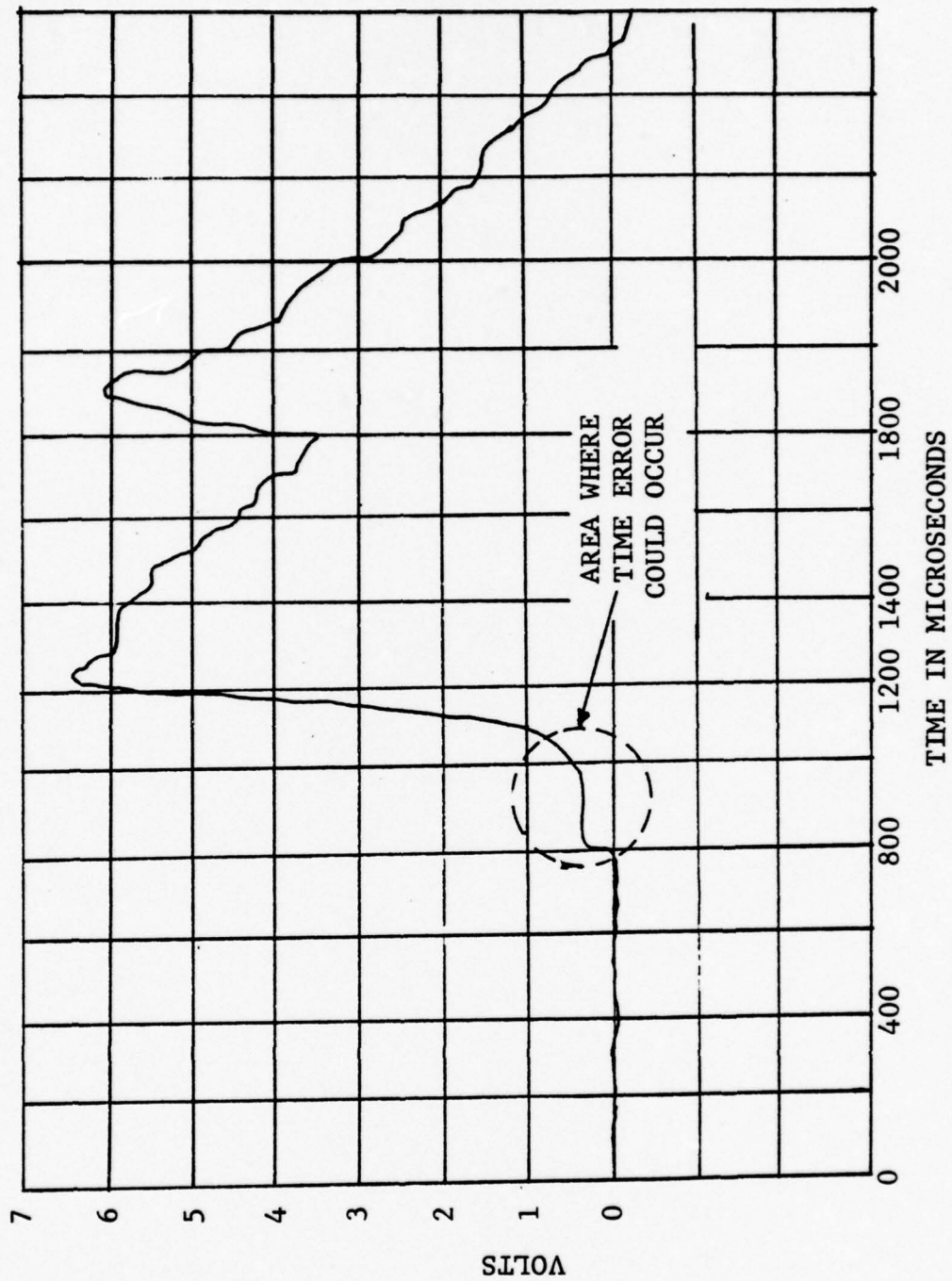


Figure 22. Pressure Trace Output from Pressure Transducer
 Locate 2.5 inches Aft of Observation Port

GUNN0037
 GUNN0038
 GUNN0039
 GUNN0040
 GUNN0041
 GUNN0042
 GUNN0043
 GUNN0044
 GUNN0045
 GUNN0046
 GUNN0047
 GUNN0048
 GUNN0049
 GUNN0050
 GUNN0051
 GUNN0052
 GUNN0053
 GUNN0054
 GUNN0055
 GUNN0056
 GUNN0057
 GUNN0058
 GUNN0059
 GUNN0060
 GUNN0061
 GUNN0062
 GUNN0063
 GUNN0064
 GUNN0065
 GUNN0066
 GUNN0067
 GUNN0068
 GUNN0069
 GUNN0070
 GUNN0071
 GUNN0072
 GUNN0073
 GUNN0074
 GUNN0075
 GUNN0076
 GUNN0077
 GUNN0078
 GUNN0079
 GUNN0080
 GUNN0081
 GUNN0082
 GUNN0083
 GUNN0086

```

T=0.0
ICATA=0
NI=0
123 M=6
      DATA NREAD,NPRINT/5,6/
      NPVITR=1
1  CALL ZEROA(500,XP1,XP2,PP1,VP2,XP3)
      CALL ZEROA(500,PP3,PP1,PP1,PP1)
      CALL ZEROA(10,ISTOPX,ISTOPX,ISTOPX,ISTOPX,ISTOPX)
      INTERJ(31)=M
      CPMAX=0.0
      PTMAX=0.0
      AMFMAX=0.0
      NTIMPT=0
      IP=0
      NPFUNCH=1
      IPNCHX=0
      LN=0
      IPV1=1
      IPV2=2
      C  IF(NPVITR.EQ.1)GO TO 41
      C  INPUT FOR INITIAL CONDITIONS FOR PROGRAM, BEGIN INPUT FOR RUN,NEW OR ITE
      NPVITR=1
      C  INPUT FOR ITERATION FROM STORAGE
      CALL STORE(ISTORM,STORM)
      EMLEAD=STORM(97)
      HYDRD1=STORM(98)
      HYDRD2=STORM(99)
      NEQST(30)=ISTORM(100)
      IF(IDATA)8,8,608
      C  CONTINUE
      INPUT FOR NEW RUN, STORAGE OF INPUT
      READ(INREAD,604)IDATA,IPRNTZ,ITRNSF,IPUNCH,DTSQ(199)
      C  604  FCFMAT(413,F10.0)
      M=6
      IF(ITRNSF.EQ.0) GO TO 619
      INTERJ(31)=M
      619  IF(IDATA)606,606,620
      608  READ(INREAD,READ1)
      ICATA=0
      GO TO 610
      606  CALL READ
      READ(INREAD,20) IPOX, NPOX,(XPO(M), M=1,NPOX)
      READ(INREAD,49) XPV1, XPV2, PVERR, PVWANT
      READ(INREAD,6)R,EMPIST,FRAC,EMLEAD
      FORMAT(E10.4,3F10.0)
      6  READ (NREAD,49) (AMOL(I),I=1,IMAX)
  
```

GUNNO085
 GUNNO084
 GUNNO087
 GUNNO088
 GUNNO089
 GUNNO090
 GUNNO091
 GUNNO092
 GUNNO093
 GUNNO094
 GUNNO095
 GUNNO096
 GUNNO097
 GUNNO098
 GUNNO099
 GUNNO100
 GUNNO101
 GUNNO102
 GUNNO103
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 GUNNO113
 GUNNO114
 GUNNO115
 GUNNO116
 GUNNO117
 GUNNO118
 GUNNO119
 GUNNO120
 GUNNO121
 GUNNO122
 GUNNO123
 GUNNO124
 GUNNO125
 GUNNO126
 GUNNO127
 GUNNO128
 GUNNO129
 GUNNO130
 GUNNO131
 GUNNO132

```

49  READ (NREAD,49) (TO(I),I=1,IMAX)
610 FORMAT(7F10.0)
    CONTINUE
    CALL STORIN (ISTORM, STORM)
    STORM(97)=EMLEAD
    STORM(98)=HYDRD1
    STORM(99)=HYDRD2
    ISTORM(100) = IPOX
    INITIAL CONDIYIONS AND CONSTANTS FOR RUN
    NPTN=NZONES(1)+NZONES(2)+NZONES(3)+1
    XSST=FRAC*OUTBDY(5)
    NEQST(30) = IPOX
    CALL CALCUL (EMLEAD)
    IF (NI.NE.0) GO TO 603
    CALL PRINT7 (EQ,0) GO TO 603
    REAC(NREAD,11) ILASTK
    IF (ILASTK) 123,12,1
    CALL SETUP
    DO 706 IMP=1, JLAST
    PMDMIN(IMP)=PPLUSQ(IMP)
    PMDMAX(IMP)=PPLUSQ(IMP)
    MAIN LOOP OF PROGRAM - DYNMEQ, LFTOVER, AND OUTPUT
    CALL DYNMEQ
    DO 710 IMP=1, JLAST
    IF (PPLUSQ(IMP).GT.PMDMIN(IMP)) GO TO 705
    PMDMIN(IMP)=PPLUSQ(IMP)
    IF (PPLUSQ(IMP).LT.PDMAX(IMP)) GO TO 710
    PMDMAX(IMP)=PPLUSQ(IMP)
    CONTINUE
    IF (IPUNCH.EQ.0 .OR. JPROJ.NE.300) GO TO 627
    PRSTAB(NPUNCH)=T-DTSQ(200)
    NPNP1=NPUNCH+1
    JPLFAF=INTERJ(6)
    J=JPLHAF
    JMNHAF=JPLHAF-1
    DUDI=26./18.*PPLUSQ(JMNHAF)-1./9.*PPLUSQ(JMNHAF-1)
    PRSTAB(NPNP1)=DUDI
    IF (I.GT.(DTSQ(200)+DTSQ(199))) GO TO 647
    PRSTAB(NPNP1)=PRSTAB(NPNP1)*(T-DTSQ(200))/DTSQ(199)
    NPUNCH=NPUNCH+2
    IF (91-NPUNCH) 625,625,627
    PUNCH 641, PRSTAB
    647  FORMAT(3(F12.8,E12.8))
  
```

GUNNO133
 GUNNO134
 GUNNO135
 GUNNO136
 GUNNO137
 GUNNO138
 GUNNO139
 GUNNO140
 GUNNO141
 GUNNO142
 GUNNO143
 GUNNO144
 GUNNO145
 GUNNO146
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627 NPUNCH=1
630 CONTINUE
672 M=6
C CONTINUE OF MAXIMUM PRESSURES
STOR51 = INTERJ(6) -1
CPMAX = AMAXI(CPMAX, PPLUSQ(NPTN-1), PPLUSQ(NPTN-2), PPLUSQ(NPTN-3))
AMPMAX = AMAXI(AMPMAX, PPLUSQ(INER51))
Determination if model has been launched
IF(XSTOP-X(JLAST,NPLUS1)) 9 3 3
ROUTINE STORAGE OF POINTS TO BE PLOTTED
3 IF(IPOX.EQ.5) GO TO 2
IF(X(NPTN, N) .LT. XSST) GO TO 2
KN=NCYCLE/6
SN=NCYCLE
TN=SN/6
4 IF(TN-QN) 4 4 2 GO TO 7
IF(LN.GT.498) GO TO 7
IF(LN = LN+1)
IF(IPOX.EQ.6) GO TO 75
XP3(LN)=PPLUSQ(NPTN)
XP4(LN)=X(NPTN-1,N)
PP4(LN)=PPLUSQ(NPTN-1)
IF(IPOX.EQ.1) GO TO 51
DC 60 IPOX=1, NPOX
IF(ISTOPX(INPOX).GE.1) GO TO 60
NTPMT=LN
DC 58 INPTN=2, JLAST1
IF(XPO(INPOX).LT.XI(INPTN)) GO TO 59
58 CONTINUE
DUMVAR(LN, INPOX)=PPLUSQ(INER51)
NPTPL(INPOX)=LN
GO TO 60
59 DUMVAR(LN, INPOX)=PPLUSQ(INPTN-1)+(PPLUSQ(INPTN-1)-PPLUSQ(INPTN))
1/(XI(INPTN-1)-XI(INPTN))*(XPO(INPOX)-XI(INPTN-1))
NPTPL(INPOX)=LN
IF(LN.EC.1099)GO TO 55
GO TO 60
55 ISTOPX(INPOX)=2
NPTPL(INPOX)=LN
60 CONTINUE
75 DUMVAR(LN, 1)=PPLUSQ(INER51)
78 IF(IPOX.EQ.6) GO TO 2

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51 IF(IPOX.EQ.2) GO TO 52
52 CONTINUE TO FIND MAX IN REGION TO GO HERE
C
7 STORAGE OF MODEL PLOTS AFTER BREAK VALVE
5 IF(JPROJ-300) 13,5,13
5 IF(IP.GT.498) GO TO 2
10 IP=IP+1
IF(XSTOP.EQ.3000.) GO TO 76
XPI(IP)=X(JLAST,N)
XP2(IP)=X(JLAST,N)
PPI(IP)=PPLUSQ(INER51)
VP2(IP)=U(JLAST, NMNHAF)
13 GO TO 2
PCINT OF RETURN TO MAIN LOOP OF PROGRAM
C
9 FINAL STORAGE OF POINTS TO BE PLOTTED, AND WRITING OF ALL PLOT TAP
IF(IPOX.EQ.5) GO TO 25
IF(IP.EQ.6) GO TO 76
IP=IP+1
XPI(IP)=X(JLAST,N)
XP2(IP)=X(JLAST,N)
PPI(IP)=PPLUSQ(INER51)
VP2(IP)=U(JLAST, NMNHAF)
GO TO 36
35 NPOX=1
36 DO 70 IPLTXT=1, NPOX
NPTTX=NPTPL(IPLTXT)
IF(NPTTX.LT.10) GO TO 70
NPTT=NPTPL(IPLTXT)
DO 80 ITXP=1, NPTT
PPLT(ITXP)=IPOX(ITXP)
PPLT(ITXP)=DUMVAR(ITXP, IPLTXT)
80 IF(JPROJ.NE.300) GO TO 1
70 CONTINUE
GO TO 25
76 DO 93 ITXP=1, LN
DUMVAR(ITXP)=DUMVAR(ITXP,1)
93 TERMINATION OF RUN, RETURN FOR NEW INPUT
C
25 READ(INREAD,11) ILASTK
IF((IPUNCH.EQ.0).OR.(NPUNCH.EQ.1)) GO TO 629
NPUNCH=NPUNCH-1
PUNCH 641, (PRSTAB(IPXX), IPXX=1, NPUNCH)
629 CONTINUE
WRITE(6,704) CPMAX, PTMAX, AMPMAX
WRITE(6,704) ((IT,PDMIN(IT),TDMIN(IT),PDMAX(IT),TDMAX(IT)
1,IT=1,JLAST))
704 FORMAT(3F20.2)
45 IF(ILASTK) 15, 12, 1

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READ(NREAD,5)CALPGM,TBURND,GMSPPDR,GASPRS,IHEL
 REAC(NREAD,123)HYDRD1,HYDRD2
 FORMAT(2E15.5)
 WRITE(6,123)HYDRD1,HYDRD2
 FORMAT(4F10.0,14)
 FORMAT(7F10.0)
 RETURN
 END
 SUBROUTINE PRINTO(EMLEAD,FRAC,XPV1,XPV2,PVWANT,NPOX,IPOX,XPO)
 PRINT DIMENSIONS AND POWDER CONDITIONS
 COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMS PDR,GASPRS,IHEL
 COMMON AREA1,AREA2,AREA3,AREA4,CALPGM,AREA5,DLAMAX,DLAMAXG
 1 DTMU,DUOT,DLAMDA,DTSQ,DTLAST,DLAST1,DJLAST,DELX,DMU,DPDE,
 2 EWRONG,EL,FORCE,GAMMA,HALFM,HALFR,HYDRD1,HYDRD2,HYDRD3,HYDRAD,
 3 OUTBDY,OUTDT1,OUTDT2,PCON1,PCON2,PPUSQ,P,PI,Q,RZTSIGSQ,SHPR,
 4 SIGMAX,SIGMIN,SKININ,SKINISQ,TVFREQ,UZER,U,USQ,TBAR,TNEXT,
 5 TVPRINT,TVNEXT,TMISCOS,X,XI,INDEX,XMIT,I,JPROCJ2,JMIN,JMAX,J,
 6 VZERO,V,VOLUME,VISINTERJ,I,ISTJLAST,JMIN,JMAX,I,K,L,LE,N,MMNHF,NPLUSI,
 7 COMMON JMNHF,JLAST,JLAST1,JMIN,NZONES,NCYCLE,IST,PO,TO,AMOL,DUMVAR,
 1 NLCATE3,NUMBER,NTV,NCKEKE,NEQST,NPROJ,JSTOR,R,EMP,CSQ(200),DQ2(200),DS(200),
 2 NPLHAF,NN,NPL3HF,NP,1,COSQX(30),DELX(30),DQ1(200),GAMMA(30),
 3 DIMENSION AREA(200),DTSQ(200),EINT(30),EIN(30),FORCE(200),NEQST(30),
 4 DTMIN(30),DLAMDA(200),HALFR(30),HYDRAD(200),INTERJ(31),MACHSQ(200),NEQST(30),
 5 HALFM(200),OUTBDY(30),PPUSQ(200),P(200,2),Q(200,2),RZERO(30),
 6 SKIN(200),TSIGSQ(200),TMINSQ(2),TOVREI(30),THETA(200),UZFERO(30),
 7 U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),
 DIMENSION XLGTH(30),ZQMASS(30),XPO(10),REGVCL(30)
 WRITE(6,65)
 FORMAT(1H1)
 XLGTH(1)=OUTBDY(1)
 REGVOL(1)=AREA*XLGTH(1)
 IF(IMAX.EQ.1)GO TO 210
 DO 200 KQX=2,IMAX
 XLGTH(KQX)=OUTBDY(KCX)-OUTBDY(KQX-1)
 KQX=IMAX-1
 DO 201 KQX=2,KQX
 REGVOL(KQX)=AREA2*XLGTH(KQX)
 REGVOL(IMAX)=AREA3*XLGTH(IMAX)
 201
 210
 ANGLE=ATAN(SLOPE)
 ANGLE=ANGLE*(360./6.2832)
 WRITE(6,100)NUMBER,NDATE1,NDATE2,NDATE3
 WRITE(6,102)IMAX,JPROJ
 I=1

123
 5
 100
 903
 65
 200
 201
 210

C

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WRITE (6,103) I,NZONES(I),XLGTH(I),AREA1,REGVOL(I)
IF(I=IMAX) GO TO 211
KQX=I
WRITE (6,103) (I,NZONES(I),XLGTH(I),AREA2,REGVOL(I),I=2,KQX)
WRITE (6,103) IMAX,NZONES(IMAX),XLGTH(IMAX),AREA3,REGVOL(IMAX)
WRITE (6,105) SLOPE,ANGLE
WRITE (6,111) CALPGM,TBURND,GMS PDR,GASPRS
WRITE (6,106) (I,NEQST(I),PO(I),TO(I),AMOL(I),CQSX4(I),I=1,IMAX)
WRITE (6,108) (I,GAMMA(I),EZERO(I),ROZERO(I),VZERO(I),I=1,IMAX)
WRITE (6,110) R
WRITE (6,114) XPV1,XPV2,PVWANT
WRITE (6,115) OUTDT1,OUTDT2,TMAX2
WRITE (6,115) EMLEAD*453.59
EMPISTX=EMPIST*453.59
XXMASX=REGVOL(IMAX)*ROZERO(IMAX)
SHPRX=SHPR*14.504
WRITE (6,112) EMLEAD,EMLEAX,EMPIST,EMPISTX,XXMAS
WRITE (6,113) SHPR,SHPRX
KQX=I
GO TO (10,11,12,12,13,14),KQX
10 WRITE (6,119) IPOX
GC TO 15
11 WRITE (6,120) IPOX
GC TO 15
12 WRITE (6,123) IPOX
GO TO 15
13 WRITE (6,121) IPOX
GC TO 15
14 WRITE (6,122) IPOX
15 WRITE (6,117) NPOX
WRITE (6,118) (XPO(I),I=1,NPOX)
WRITE (6,65)
RETURN
FORMAT (23X,36HHYPERVELOCITY MODEL LAUNCHER PROGRAM//22X,19HCOMPUTE)
100 1R RUN NUMBER,15 7H DATE,12 1H/,12 1H/,12 1H/
102 1//12X,6HREGION,5X,5H ZONES,31X,12,10H REGIONS,13,6H ZONES,4G
2H(CM),9X,6H(CMSQ),11X,4H(CC/1H)
103 FCRMAT (14X,12,9X,12,2X,F10.2,5X,F10.2,7X,F10.2)
104 FCRMAT (14X,12,9X,12,2X,F10.2,11X,3H---,12X,3H---)
105 FCRMAT (1H,19X,7HSLOPE =,F8.4,9X,7HANGLE =,F6.2,5H DEG)
106 FCRMAT (1H,5X,12HMATERIALS --//7X,6HREGION,5X,5HNEQST,5X,8HPRESSUR
1E,7X,4HTEMP,9X,8HMOLEC WT,6X,6HCQSX4/30X,5H(PST),6X,7H(DEG K),7X,
29F(GM/MOLE)/1H)
108 FCRMAT (9X,12,8X,12,5X,F9.2,6X,F7.2,6X,F9.4,6X,F5.1)

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109 FORMAT(1H /6X,6HREGION,4X,5HGAMMA,9X,6HENERGY,10X,7HDENSITY,9X,9HSGUNNO373
1P VOLUME/26X,13H(BARS-CC/CCO),7X,7H(GM/CC),5X,8H(CC/CCO)/1H ) GUNNO374
110 FORMAT(8X,12,5X, F6.3,6X, E11.4,6X, E11.4,6X, E11.4) GUNNO375
111 FORMAT(1H //32X, 18HINITIAL CONDITIONS, 20HPOWDER CONDITIONS --//GUNNO376
114X,8HCALPGM =,F12.4,6X,8HTBURND =,F12.4,4,5H PSI) GUNNO377
212 4,6X,8HGASPRS =,F12.4,5H PSI) GUNNO378
112 FORMAT(1H /5X,10HWEIGHTS --//9X,6HPISTON/13X,23HMASS OF FIRST SECT,GUNNO379
11CN =,F13.4,4H LB,8X,1H=,F13.4,4H GM/13X,24HMASS OF SECOND SECT,GUNNO380
20N =,F12.4,4H LB,8X,1H=,F13.4,4H GM//9X,5HMODEL/13X,15HMASS OF MGUNNO381
30CEL =,F12.4,4H GM) GUNNO382
113 1,10X,22HBREK VALVE STRENGTH =,F10.2,6H BARS,5X,1H=,F10,GUNNO383
2,5H PSI) GUNNO384
114 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO385
2//SEC) GUNNO386
115 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO387
2//SEC) GUNNO388
116 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO389
2//SEC) GUNNO390
117 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO391
2//SEC) GUNNO392
118 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO393
2//SEC) GUNNO394
119 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO395
2//SEC) GUNNO396
120 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO397
2//SEC) GUNNO398
121 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO399
2//SEC) GUNNO400
122 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO401
2//SEC) GUNNO402
123 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO403
2//SEC) GUNNO404
124 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO405
2//SEC) GUNNO406
125 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO407
2//SEC) GUNNO408
126 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO409
2//SEC) GUNNO410
127 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO411
2//SEC) GUNNO412
128 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO413
2//SEC) GUNNO414
129 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO415
2//SEC) GUNNO416
130 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO417
2//SEC) GUNNO418
131 1,FCRMA(1H /5X,18HPISTON VELOCITY --//10X,6HXPV1 =,F10.2,7H CM GUNNO419
2//SEC) GUNNO420

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C


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5SKIN(200), TSIGSQ(200), TMINSQ(2), TOVRE1(30), THETA(200), UZERO(30),
6U(201), USQ(201), VZERO(30), V(200,2), VISCOS(200), X(201,2), X1(200),
7ZMASS(200), PO(30), TO(30), AMOL(30), DUMVAR(500,5)
DTLAST=DTMIN(NPLHAF)
M=INTERJ(31)
IF(SIGMAX.EQ.C.0)GO TO 240
SIGMIN=1./SIGMAX
GC TO 244
SIGMIN=0.
240 IF(SIGMIN-.7.41*TMINSQ(NPLHAF)) 270,270,250
244 IF(DLAMAX-.079) 255,270,270
250 IF(SIGMIN-11.11*TMINSQ(NPLHAF)) 265,260,260
255 IF(DLAMAX-.065) 270,270,265
260 TMINSQ(NPL3HF)=TMINSQ(NPLHAF)
265 GC TO 285
IF(DLAMAX-.01) 275,275,280
270 IF(DLAMAX-.01) 275,275,280
275 TMINSQ(NPL3HF)=SIGMIN/2.25
GC TO 285
280 TMINSQ(NPL3HF)=AMINI(SIGMIN/9.00;.005184*TMINSQ(NPLHAF)/DLAMA X**2)
285 DTMIN(NPL3HF)=AMINI(SQRT(TMINSQ(NPL3HF)),1.4*DTMIN(NPLHAF))
290 DTMIN(NN)=(DTMIN(NPL3HF)+DTMIN(NPLHAF))/2.
NP=NPLUS1
NPLUS1=N
NPLHAF=NPLUS1
N=NP
NMNHAF=N
NPL3HF=N
EINSUM=0.
EKSUM=0.
USQ(1)=U(1,N)**2
DO 300 I=1,IMAX
EINT(I)=0.
EKIN(I)=0.
JMAX=INTERJ(I)-1
DO 295 J=JMIN,JMAX
JPLHAF=J
USQ(J+1)=U(J+1,N)**2
X1(JPLHAF)=(X(J,N)+X(J+1,N))/2.
EINT(I)=EINT(I)+E(JPLHAF,N)/HALFRO(I)*HALFM(JPLHAF)
EKIN(I)=(USQ(J)+USQ(J+1))*HALFM(JPLHAF) +EKIN(I)
EINSUM=EINSUM+EINT(I)
EINSUM=EINSUM+EINT(I)
EKSUM=5*EMPROJ*U(JLAST,NMNHAF)**2+EKIN(6)
EKSUM=EKSUM+EKIN(I)
EKSUM=EINSUM+EKSUM
300

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49 WRITE(M,1)K,NUMBER,NDATE1,NDATE2,NDATE3
51 WRITE(M,6) NCYCLE,T,DTLAST,ESUM
52 IF(NCYCLE) 53,53,400
53 DC 57 JPLHAF=1,JLAST1
57 ZMASS(JPLHAF)=2.*HALFM(JPLHAF)
60 WRITE(M,3)
WRITE(M,5555)
DC 604 L=1,JLAST1
DO 602 IL=2,LIMIT
IF(L-INUE) 602,603,602
602 CONTINUE(4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),
1E(L,N),AREA(L,N),DTSQ(L),ZMASS(L)
GC TO 604
603 WRITE(M,5556)
5556 FFORMAT(IHO)
WRITE(M,4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),
1E(L,N),AREA(L,N),DTSQ(L),ZMASS(L)
604 CCNTINUE(4) JLAST,X(JLAST,N),U(JLAST,NMNHAF)
GC TO 71
400 NYCRA2=HYDR2
IF((NYDRA2.EQ.0).OR.((NYDRA2-60).EQ.0).DR.((NYDRA2-30).EQ.0))
1 GO TO 100
IF((NYDRA2.GT.30).AND.(NYDRA2.LT.60)) GO TO 300
IF((NYDRA2.GT.60) GO TO 600
NZN=1
MZN=INTERJ(NYDRA2+1)-1
GO TO 200
NYCRA2=NYDRA2-30
NZN=INTERJ(NYDRA2)
MZN=INTERJ(NYDRA2+1)-1
GO TO 200
600 NYDRA2=NYDRA2-60
NZN=INTERJ(NYDRA2)
MZN=JLAST1
DO 70 JK=NZN,MZN
JKM=JK-NZN+1
XP6(JKM)=X1(JK)
VP6(JKM)=U(JK,NMNHAF)/100.
PP5(JKM)=PPLUSQ(JK)
70 CCNTINUE(M,7)
100 WRITE(M,8)
WRITE(M,5555)

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DC 704 L=1,JLAST1
 DO 702 IL=2,ILIMIT
 IF(LT-INTERJ(IL)) 702,703,702
 702 CCNTINUE(4) L,X(L,N),U(L,NMNHAF),V(L,N),PPLUSQ(L),Q(L,NMNHAF),
 1E(L,N),AREA(L,N),DTSQ(L),X1(L)
 GC IO 704
 703 WRITE(M,5555)
 5555 FORMAT(IH)
 1E(L,N),AREA(L,N),DTSQ(L),X1(L)
 704 CONTINUE(4) JLAST,X(JLAST,N),U(JLAST,NMNHAF)
 71 WRITE(M,9)
 75 WRITE(M,10) (I,NEQST(I),EKIN(I),EINT(I),I=1,IMAX)
 5 IF(EMRONG) 95,95,80
 80 WRITE(M,11)
 95 RETURN
 40 FORMAT(115,1P7E13.5) H V MODEL LAUNCHER,4I3)
 1 FCRVAT(118HO J X(J,N) U(J,N-1/2) V(J+1/2,N) P(J+1/2,N)
 1) Q(J+1/2,N-1/2) E(J+1/2,N) AREA(J,N) DTSQ(1/2,1/2) DM(J+1/2)
 3) FFORMAT(114H CM/MILLISEC MILLISECSQ GRAMS)
 4) FFORMAT(14,1P6E13.5) BARS-CC/CCO
 6) FFORMAT(119HO J X(J,N) U(J,N-1/2) V(J+1/2,N) P(J+1/2,N)
 1) Q(J+1/2,N-1/2) E(J+1/2,N) AREA(J,N) DTSQ(1/2,1/2) X(J+1/2,N)
 8) FCRVAT(114H CM/MILLISEC MILLISECSQ CM)
 1) FFORMAT(146HOREGION MATERIAL K-ENERGY I-ENERGY
 9) FFORMAT(15,18) BARS-CC/CCO ENERGY CHECK)
 10) FFORMAT(15H1) MATERIAL 2E15.5) TOTAL E)
 12) FFORMAT(17HOCYCLE T DT
 END
 SUBROUTINE CALCUL (EMLEAD)
 C&L CUL REGIONAL ENERGY, SPECIFIC VOLUME, AND DENSITY
 COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMS PDR,GASPRS,IHEL
 COMMON AREA1,AREA2,AREA3,AREA4,CMA XR,CSCG,CSQMAX,CP,CMU,DLAMAX
 1) DTMIN,DQ1,DQ2,DS,EZERO,EIN,ESUM,EKIN,EJET,ELENTH,
 2) PCMU,EI,FDL,OUTDT2,PCON1,PCON2,PPUSQ,P.1,9,ROZTSI,CSQ,HPR,
 3) OUTBDY,OUTGMIN,SKIN,TMAX1,TMAX2,VDTI,TVDT2,T,IMAX,ITNEXT,
 5) SIGMAX,SIGMIN,SKIN,TMINSQ,TVFREQ,UZZERO,U,USQ,TBAR,TOVREI,TWALL,
 6) PRINT,TVNEXT,TMINSQ,TVFREQ,UZZERO,U,USQ,TBAR,TOVREI,TWALL,

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7 VZERO, V, VOLUME, VISCOS, X, XI, XGRID, XMIN, XMAX, ZMASS, EMPROJ, XSTOP
COMMON I, INU, I, INTERJ, INDEX, ILIMIT, JPROJ, JPROJ2, JMIN, JMAX, J,
1 JPLHAF, JMNHAF, JLAST, JMIN1, JMAX1, K, L, MACHSQ, NDAT, E2,
2 NCATE3, NTV, NCHEKE, NOST, NZONES, NCYCLE, N, NMNHAF, NPLUS1,
3 NPLHAF, NN, NPL3HF, NP, 2, IQUIT, JPROJ, JSTOP, R, EMP1ST, PO, TO, AMOL, DUMVAR
4 DIMENSION ON, AREA(200, 2), COSQ(200), DELX(30), DQ1(200), DQ2(200), DS(200),
5 DMIN(30), DLAMDA(200), DTSG(200), EKIN(30), FORC(200), GAMMA(30), NEQST(30)
6 EZERO(30), HALFRQ(30), HYDRAD(200), INTERJ(31), MACHSQ(200), ROZERO(30),
7 HALFM(200), OUTBDY(200), PPLUSQ(200), P(200, 2), Q(200, 2), ROZERO(30),
8 NZONES(30), TSGSQ(200), TMINUSQ(200), TDVREI(30), THETA(200), UZERO(30),
9 SKIN(200), USQ(200), VZERO(30), V(200, 2), VISCOS(200), X(201, 2), X1(200),
10 SU(201, 2), VZERO(30), TO(30), AMOL(30), DUMVAR(500, 5)
11 M=INTERJ(31)
12 DO 50 I=1, IMAX
13 RCZERO(I)=AMOL(I)/22.4E3
14 VZERO(I)=R*TO(I)/PO(I)/AMOL(I)*14.5/1.E6*ROZERO(I)
15 EZERO(I)=PO(I)*VZERO(I)/(GAMMA(I)-1.)/14.5
16 WRITE(M, I1)
17 FORMAT(IH1)
18 DO 25 IK=1, IMAX
19 IF (PO(IK).NE.1.0) GO TO 23
20 GAMMA(IK)=1.0
21 EZERO(IK)=1.0
22 VZERO(IK)=1.0
23 RCZERO(IK)=EMLEAD*453.7/(AREA2*(OUTBDY(2)-OUTBDY(1)))
24 IF (PO(IK).NE.2.0) GO TO 24
25 GAMMA(IK)=1.0
26 VZERO(IK)=1.0
27 RCZERO(IK)=EMPIST*453.7/(AREA2*(OUTBDY(3)-OUTBDY(2)))
28 IF (PO(IK).NE.3.0) GO TO 25
29 GAMMA(IK)=1.0
30 VZERO(IK)=1.0
31 RCZERO(IK)=EMPROJ/(AREA3*(OUTBDY(6)-OUTBDY(5)))
32 EMPROJ=0.0
33 CONTINUE
34 RETURN
35 READ
36 SLROUTINE ZEOAB
37 ZEROS ALL VARIABLES BETWEEN RUNS
38 COMMON PCON3, SLOPE, RADIUS, CALPGM, TBURND, GMS PDR, GASPRS, IHEL, V, DLAMA, X
39 COMMON AREA1, AREA2, AREA3, AREA4, CMA, XR, CSQ, CSQMAX, CP, CMU, DPDE,
40 COMMON QUT, DLAMDA, DTSG, DTLAST, DLAST, DJLAST, DNZONE, DELX1, CMU, DPDE,
41 DPMU, DQ1, DQ2, DS, EZERO, EINSUM, ESUM, EKIN, EINT, EKIN, E, ETOI, ETENTH,
42 PRONG, EL, FORC, GAMMA, HALFM, HALFRQ, HYDRAD, HYDRD3, HYDR,
43 OUTBDY, OUTDT1, OUTDT2, PCON1, PCON2, PPLUSQ, P, P1, Q, ROZERO, SHPR,
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CALL ZEROB(E,200,2)
CALL ZEROB(AREA,200,2)
CALL ZEROB(Q,200,2)
CALL ZEROB(U,201,2)
CALL ZEROB(V,200,2)
CALL ZEROB(P,200,2)
CALL ZEROB(X,201,2)
RETURN
END
SUBROUTINE IERD(I1,I2,I3,I4,I5,I6,I7,I8)
ZEROS INTEGERS
I1=0
I2=0
I3=0
I4=0
I5=0
I6=0
I7=0
I8=0
RETURN
END
SUBROUTINE ZERO(Z1,Z2,Z3,Z4,Z5,Z6,Z7,Z8)
ZEROS NON-INTEGERS
Z1=0.
Z2=0.
Z3=0.
Z4=0.
Z5=0.
Z6=0.
Z7=0.
Z8=0.
RETURN
END
SUBROUTINE ZERDA(IZA,ZA1,ZA2,ZA3,ZA4,ZA5)
ZEROS VECTORS
DIMENSION ZA1(300),ZA2(300),ZA3(300),ZA4(300),ZA5(300)
DO 1 IZZ=1, IZA
ZA1(IZZ)=0.
ZA2(IZZ)=0.
ZA3(IZZ)=0.
ZA4(IZZ)=0.
ZA5(IZZ)=0.
1 CONTINUE
RETURN
END
SUBROUTINE ZEROB(ZAB,IZA,IJB)
ZEROS ARRAYS
DIMENSION ZAB(300,10)

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DO I=1, I MAX
  IN+10=IN+10
  IN+20=IN+20
  IN+30=IN+30
  IN+40=IN+40
  IN+50=IN+50
  IN+60=IN+60
  ISTOREM(IN10)=NEQST(IN)
  ISTOREM(IN20)=NZONES(IN)
  ISTOREM(IN30)=OUTBDY(IN)
  ISTOREM(IN40)=GAMMA(IN)
  ISTOREM(IN50)=CQSQX4(IN)
  ISTOREM(IN60)=UZERO(IN)
  ISTOREM(IN70)=PO(IN)
  ISTOREM(IN80)=TO(IN)
  ISTOREM(IN90)=AMOL(IN)
  ICONTINUE
  ISTOREM(71)=AREA1
  ISTOREM(72)=AREA2
  ISTOREM(73)=AREA3
  ISTOREM(74)=PCON1
  ISTOREM(75)=PCON2
  ISTOREM(76)=SHPRK
  ISTOREM(77)=EMPROJ
  ISTOREM(78)=OUTDT1
  ISTOREM(79)=TMAX1
  ISTOREM(80)=TMAX2
  ISTOREM(81)=XSTOP
  ISTOREM(82)=PCON3
  ISTOREM(83)=SLOPE
  ISTOREM(84)=RADIUS
  ISTOREM(85)=CALPGM
  ISTOREM(86)=TBURND
  ISTOREM(87)=GMSPPDR
  ISTOREM(88)=GASPRS
  ISTOREM(89)=R
  ISTOREM(90)=EMPISI
  ISTOREM(91)=PVWANT
  ISTOREM(92)=PVSLPE
  ISTOREM(93)=XPV1
  ISTOREM(94)=XPV2
  ISTOREM(95)=PVERR
  ISTOREM(96)=PRESCG
  ISTOREM(97)=PRESCG
  RETURN
END
SUBROUTINE STORE (ISTORM, STORM)
STORAGE ROUTINE
  
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3  HALF(200), HALFRO(30), HYDRAD(200), INTERJ(31), MACHSQ(200), NEQST(30) GUNN0997
4  NZONES(30), OUTBDY(30), PPLUSQ(200), P(200,2), Q(200,2), RZERO(30), GUNN0998
5  KIN(200), SIGSQ(200), MINUSQ(2), TOVREI(30), THETA(200), UZERO(30), GUNN0999
6  U(201,2), USQ(201), VZERO(30), V(200,2), VISCOS(200), X(201,2), X1(200), GUNN1000
7  ZMASS(200), PO(30), TO(30), AMOL(30), DUMVAR(500,5) GUNN1001
35  I=1, IMAX GUNN1002
    DC HALFRO(I)=RZERO(I)/2. GUNN1003
    INTERJ(I)=1 GUNN1004
    I=1, IMAX GUNN1005
40  INTERJ(I+1)=INTERJ(I)+NZONES(I) GUNN1006
    JLAST=INTERJ(IMAX+1) GUNN1007
    JLAST1=JLAST-1 GUNN1008
    JLAST1=JLAST GUNN1009
    CLAST1=JLAST1 GUNN1010
    DNZCNE=NZONES(I) GUNN1011
    DELX(I)=OUTBDY(I)/DNZONE GUNN1012
    X(1:N)=0. GUNN1013
    U(1,NMNHAF)=UZERO(I) GUNN1014
    DC 45 I=2, IMAX GUNN1015
    DNZONE=NZONES(I) GUNN1016
    DELX(I)=(OUTBDY(I)-OUTBDY(I-1))/DNZONE GUNN1017
45  CC 55 I=1, IMAX GUNN1018
    JMIN=INTERJ(I)+1 GUNN1019
    JMAX=INTERJ(I+1)-1 GUNN1020
    DC 50 J=JMIN, JMAX GUNN1021
    JMNHAF=J-1 GUNN1022
    U(J,NMNHAF)=UZERO(I) GUNN1023
    V(JMNHAF,N)=VZERO(I) GUNN1024
    E(JMNHAF,N)=EZERO(I) GUNN1025
50  X(J,N)=X(J-1,N)+DELX(I) GUNN1026
    X(J,N)=X(J,N)+1, NMNHAF) GUNN1027
    U(J,N)=UZERO(I) GUNN1028
    E(J,N)=EZERO(I) GUNN1029
55  V(J,N)=VZERO(I) GUNN1030
    DC 132 J=1, JLAST GUNN1031
    CALL ARCOMP GUNN1032
65  DO 130 I=1, IMAX GUNN1033
    JMIN=INTERJ(I)+1 GUNN1034
    JMAX=INTERJ(I+1) GUNN1035
    DC 125 J=JMIN, JMAX GUNN1036
    JMNHAF=J-1 GUNN1037
120  CALL VCJMP GUNN1038
    FCFM(JMNHAF)=HALFRO(I)/V(JMNHAF,N)*VOLUME GUNN1039
125  CCNTINUE GUNN1040
    HALFFM(JLAST)=HALFM(JLAST)+EMPROJ GUNN1041
    INDEX=NEQST(I) GUNN1042
    IF(INDEX.EQ.1)CALL ECST1 GUNN1043
    IF(INDEX.EQ.2)CALL ECST2 GUNN1044

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IF(INDEX.EQ.3)CALL EQST3
CONTINUE
CO 135 JMNHAF=1,JLAST1
135 PPLUSQ(JMNHAF)=P(JMNHAF,N)
150 DK1=2.
155 EKSUM=0.
EKSUM=0.
ETOT=0.
USQ(I)=U(1,N)**2
DO 165 I=1,IMAX
  EKIN(I)=0.
  EKIN=INTERJ(I+1)-1
  JMAX=JMIN,JMAX
  DO 160 J=JMIN,JMAX
    JPLHAF=J
    USQ(J+1)=U(J+1,N)**2
    EKIN(I)=EINT(I)+E(JPLHAF,N)/HALFRO(I)*HALFM(JPLHAF)*DK
    EKIN(I)=(USQ(J)+USQ(J+1))*HALFM(JPLHAF)*DK+EKIN(I)
    EKIN(I)=5*EKIN(I)
    EKSUM=EINSUM+EINT(I)
    EKSUM=EKSUM+EKIN(I)
    ETOT=EINT
    ETENTH=.125*(X(JMAX,N)-X(1,N))
    XGRIN=X(1,N)-XGRID
    XMAX=X(JMAX,N)+XGRID
    CALL OUTPUT
    RETURN
  END
SUBROUTINE DYNMEQ
CALCULATES MASS POINT VELOCITY AND ZONE SPECIFIC VOLUME AND
BCUNDARIES
CCCOMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMS PDR,GASPRS,IHEL
CCCOMMON AREAL,AREA2,DTLAS,DTSQ,DTLAST,CMAXRST,CSQ,CSQMAX,CP,CMU,CPDE,
1 20PCMU,DQ1,DQ2,DS,EZERO,EINSUM,ESUM,EKSUM,EI,AIN,DELX,ETOT,ETENTH,
3EWRCNG,EI,FDI,OUTDT2,PCON1,PCON2,PPLUSQ,PI,QR,ZDR3,HYDRAD,
4OUTBDY,OUTDT1,SKIN,IMAX2,IVDT1,IVDT2,IMAX,ISIGSQ,SHPR,INEXT,
5SIGMAX,SIGMIN,TVNEXT,TMINSQ,TVFREQ,UZERO,UIN,XMAX,ZMASS,EMPROJ,XSTOP,
6TVPRINT,VOLUME,VINU,IX,XI,XGRID,XMIN,XMAX,JPROJ,J2,JMIN,JMAX,J,
7VZERO,IMAX,F,JA,INTERJ,IMINI,JMAX1,K,L,MACHSQ,NDAT,E2,
1JPLHAF,JMNHAF,JLAST,JLAST1,JMINI,JMAX1,K,L,MACHSQ,NDAT,E1,NDAT,E2,
2NDATE3,NUMBER,NTV,NCHEKE,NCHEKE1,NCHEKE2,NCHEKE3,NCHEKE4,NCHEKE5,
3NPLHAF,NN,NPL3HF,NP,IQUIT,JPROJ,JSTOP,R,EMPIST,PO,TO,AMOL,DUMVAR

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DIMENSION AREA(200,2), CQSQX4(30), CMAXR(30), CSQ(200), CP(30), CV(30), GUNN1093
1DTMIN(3), DLAMDA(200), DTSQ(200), DELX(30), DQ1(200), DQ2(200), DS(200), GUNN1094
2EZERO(30), EI(200,2), EKIN(30), EKIN(30), FORCE(200), GAMMA(30), GUNN1095
3HALFM(200), HALFRD(30), HYDRAD(200), INTERJ(31), MACHSQ(200), NEQST(30), GUNN1096
4NZONES(30), OUTBDY(30), PPLUSQ(200), P(200,2), Q(200,2), RZERO(30), GUNN1097
5SKIN(200), SIGSQ(200), TMINSQ(2), TOVREI(30), THETA(200), UZERO(30), GUNN1098
6U(201,2), USQ(201), VZERO(30), V(200,2), VISCOS(200), X(201,2), X1(200), GUNN1099
7ZMASS(200), PO(30), TO(30), AMOL(30), DUMVAR(500,5), GUNN1100
C 120 I=1 GUNN1101
120 CCNTINUE GUNN1102
125 SIGMAX=0. GUNN1103
T=T+DTMIN(NPLHAF) GUNN1104
NCYCLE=NCYCLE+1 GUNN1105
DO 245 I=1,IMAX GUNN1106
NZN=ZNONES(I+1) GUNN1107
CMAXR(I)=0. GUNN1108
CSCMAX=0. GUNN1109
JMIN=INTERJ(I)+1 GUNN1110
JMAX=INTERJ(I+1) GUNN1111
DO 230 J=JMIN,JMAX GUNN1112
JPLHAF=J GUNN1113
JMNHAF=J-1 GUNN1114
IF(JLAST-J) 155,155,1700 GUNN1115
DUOT=PPLUSQ(JMNHAF)*AREA(JLAST,N)/HALFM(JMNHAF) GUNN1116
155 IF(JPROJ.EQ.300.AND.E(JMNHAF,N).NE.0.0) GC TO 195 GUNN1117
GO TO 901 GUNN1118
IF(JPROJ.EQ.300) GO TO 1755 GUNN1119
IF(J.EQ.INTERJ(6)) GO TO 901 GUNN1120
IF(J.GT.INTERJ(6)) GO TO 902 GUNN1121
GC TO 1755 GUNN1122
IF(PPLUSQ(JMNHAF)-SHPR) 902,903,903 GUNN1123
901 U(J,NPLHAF)=0.0 GUNN1124
902 U(J,NPLHAF)=0.0 GUNN1125
903 JPROJ=500 GUNN1126
DTSQ(200)=T GUNN1127
IF(J.EQ.JMAX.AND.NZN.EQ.1) GO TO 876 GUNN1128
IF(J.EQ.JMAX.AND.NZN.GT.1) GO TO 800 GUNN1129
DUOT=(PPLUSQ(JMNHAF)-PPLUSQ(JPLHAF))*AREA(J,N)/(HALFM(JMNHAF)+ GUNN1130
1HALFM(JPLHAF)) GUNN1131
GC TO 195 GUNN1132
IF(J.EQ.INTERJ(6)) GO TO 863 GUNN1133
DUOT=-1.5*(PPLUSQ(JPLHAF)-PPLUSQ(JMNHAF))-(PPLUSQ(JPLHAF+1)- GUNN1134
1PPLUSQ(JMNHAF-1))/6.*AREA(J,N)/(HALFM(JMNHAF)+HALFM(JPLHAF)) GUNN1135
GC TO 195 GUNN1136
DUOT=-1.5*(PPLUSQ(JPLHAF)-PPLUSQ(JMNHAF))-(PPLUSQ(JPLHAF+1)- GUNN1137
1(PPLUSQ(JMNHAF-1)+2.*PPLUSQ(JMNHAF-1))/3.) GUNN1138
1)/6.*AREA(J,N)/(HALFM(JMNHAF)+HALFM(JPLHAF)) GUNN1139

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154 IF(T,GE,(DTSQ(200)+DTSQ(199))) GO TO 194
    DUDT=DUDT*(T-DTSQ(200))/DTSQ(199)
    CONTINUE
    GO TO 195
876 A=2.*HALFM(JMNHAF)+HALEM(JPLHAF)
    B=HALFM(JMNHAF)+HALEM(JPLHAF)
    DUDT=((12.*A**2*PPLUSQ(JPLHAF))
1-((2.*A-B)*(A+B)*PPLUSQ(LMNHAF))
2+(A-B)*B*PPLUSQ(JMNHAF-1))/A*(A+B)*B)*(-1.)*AREA(J,N)
195 U(J,NPLHAF)=U(J,NMNHAF)+DTMIN(NN)*DUDT
196 X(J,NPLUS1)=X(J,N)+DTMIN(NPLHAF)*U(J,NPLHAF)
    CALL ARCOMP
    CALL VCQMP
    V(JMNHAF,NPLUS1)=HALFRO(I)/HALEM(JMNHAF)*VOLUME
200 IF(L(J,NPLHAF)-U(J-1,NPLHAF)) 205,225,225
205 Q(JMNHAF,NPLHAF)=CQSQX4(I)*HALFRO(I)*U(J,NPLHAF)-U(J-1,NPLHAF)
1#2/(V(JMNHAF,NPLUS1)+V(JMNHAF,N))
    GO TO 230
225 C(JMNHAF,NPLHAF)=0.
230 CONTINUE
    INDEX=NEOST(I)
    IF(INDEX.EQ.1)CALL ECST1
    IF(INDEX.EQ.2)CALL ECST2
    IF(INDEX.EQ.3)CALL ECST3
53 DO 240 J=JMIN,JMAX
    JMNHAF=J-1
    IF(JPROJ.LT.300.AND.J.GT.INTERJ(6)) GO TO 24
    T SIGSQ(JMNHAF)=CSQ(JMNHAF)/(X(J,NPLUS1)-X(J-1,NPLUS1))*2
24 CONTINUE
    PPLUSQ(JMNHAF)=P(JMNHAF,NPLUS1)+Q(JMNHAF,NPLHAF)
    DLAMDA(JMNHAF)=CQSQX4(I)/2.*(V(JMNHAF,N)-V(JMNHAF,NPLUS1))/
1(V(JMNHAF,N)+V(JMNHAF,NPLUS1))
    CFANGED TO MAX1 JANUARY 16, 1967 DKS
    DLAMAX=MAX1(DLAMDA(JMNHAF),DLAMAX)
    SIGMAX=MAX1(TSIGSQ(JMNHAF),SIGMAX)
    CSCMAX=MAX1(CSQMAX,CSQ(JMNHAF))
    IF(TSIGSQ(JMNHAF).NE.0.0) GO TO 240
    DTSQ(JMNHAF)=0.0
    GO TO 245
240 DTSQ(JMNHAF)=111111/TSIGSQ(JMNHAF)
245 CMAXR(I)=SQRT(CSQMAX)
340 CONTINUE
246 RETURN
END
SUBROUTINE ARCOMP
  DETERMINE ZONE CROSS SECTIONAL AREA
  COMMON PCON3,SLOPE,RADIUS,CALPGM,TBURND,GMSFDR,GASPRS,IHEL
  COMMON AREAL,AREA2,AREA3,AREA,CQSQX4,CMAXR,CP,CV,DLAMAX,NPLUS1)

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2EZERO(30),E(200,2),EINT(30),EKIN(30),FORCE(200),GAMMA(30),NEQST(30)
3FALFM(200),HALFRD(30),HYDRAD(200),INTERJ(31),MACHSQ(200),ROZERO(30)
4NZNONES(30),OUTBODY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30)
5SKIN(200),SIGSQ(200),TMINSQ(2),TOVREI(30),THETA(200),UZERO(30)
6U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),
7ZMASS(200),PO(30),TO(30),AMOL(30),DUMVAR(50,5)
XPV1=0.
XPV2=0.
PVERR=0.
PRESCG=0.
IF(X(J,NPLUS1)-PCON1) 3,3,4
3VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA1
GO TO 17
IF(X(J,NPLUS1)-PCON2) 5,5,8
4VOLUME=(X(J,NPLUS1)-PCON1)*AREA2+PCON1-X(J-1,NPLUS1)*AREA1
GO TO 17
5VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2
GO TO 17
6VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2
GO TO 17
7VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2
GO TO 17
8VOLUME=(X(J,NPLUS1)-PCON3) 9,9,12
IF(X(J,NPLUS1)-PCON2) 10,11,11
9VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2
GO TO 17
10VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2
GO TO 17
11VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA2
GO TO 17
12VOLUME=(X(J,NPLUS1)-PCON3) 14,13,13
IF(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3
GO TO 17
13VOLUME=(X(J,NPLUS1)-PCON2) 16,15,15
IF(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3
GO TO 17
14VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3
GO TO 17
15VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3
GO TO 17
16VOLUME=(X(J,NPLUS1)-X(J-1,NPLUS1))*AREA3
GO TO 17
17RETURN
END
SUBROUTINE EQST1
CALCULATES PRESSURE AND ENERGY FOR IDEAL GAS ZONES
COMMON PCON3,AREA3,AREA2,AREA1,COSQX4,CMA,XR,CSQ,CSQMAX,CP,CV,DLAMAX,
1,DTMIN,DQ1,DQ2,DS,EZERO,EINUM,HALFRD,HYDRD1,HYDRD2,HYDRD3,HPR,
2PDMON,DELX,DELX1,DELX2,DELX3,DELX4,DELX5,DELX6,DELX7,DELX8,
3EWRONG,ELI,ELI1,ELI2,ELI3,ELI4,ELI5,ELI6,ELI7,ELI8,ELI9,ELI10,
4OUTBODY,OUTDT1,OUTDT2,OUTDT3,OUTDT4,OUTDT5,OUTDT6,OUTDT7,OUTDT8,
5SIGMAX,SIGMIN,SKIN,SMAX,SMIN,ST,ST1,ST2,ST3,ST4,ST5,ST6,ST7,ST8,
6TVPRINT,TVNEXT,TVNEXT1,TVNEXT2,TVNEXT3,TVNEXT4,TVNEXT5,TVNEXT6,TVNEXT7,
7VZERO,V,VMAX,VMIN,X,X1,X2,X3,X4,X5,X6,X7,X8,X9,X10,X11,X12,X13,X14,
1JPLHAF,JMNHAF,JLST,JLST1,JLST2,JLST3,JLST4,JLST5,JLST6,JLST7,JLST8,
2NCATE3,NUMBER,NTV,NCHEKE,NEQST,NZNONES,NCYCLE,N,MNHNHAF,NPLUS1,

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IBURND=0
TOLD=0.
INTERJ(30)=2
ZMASS(200)=2
GASPRS=GASPR$/14.5
PVOL=GMSPDR/1000.
GVOL=PCONI*AREAL*.001-PVOL
GMOLES=GASPRS*GVOL/24.61
PMOLES=GMSPDR/25.
PRESUR=(GMOLES+PMOLES)*24.61/(GVOL+PVOL)*1.0138
IF(IHEL)40,40,35
GAMMA(I)=(GMOLES*1.667+PMOLES*1.23)/(GMOLES+PMOLES)
WGTMOL=(GMOLES*4.0026+PMOLES*25.1)/(GMOLES+PMOLES)
GO TO 50
GAMMA(I)=(GMOLES*1.4+PMOLES*1.23)/(GMOLES+PMOLES)
WGTMOL=(GMOLES*2.17+PMOLES*25.1)/(GMOLES+PMOLES)
SPCVOL=83.17*300.0/(PRESUR*WGTMOL)
ROZERO(I)=WGTMOL/22400.
VZERO(I)=SPCVOL*ROZERO(I)
VZERO(I)=PRESUR*VZERO(I)/(GAMMA(I)-1.)
JMINI=JMIN-1
JMAXI=JMAX-1
DO 20 J=JMINI,JMAXI
E(J,N)=EZERO(I)
V(J,N)=VZERO(I)
EPEAK=CALPGM*41.84*ROZERO(I)*PMOLES*25.0/(PMOLES*25.0+GMOLES*2.0)
HALFR(I)=ROZERO(I)/2.
DO 30 J=JMIN,JMAX
VOLUME=(X(J,N)-X(J-1,N))*AREAL
HALFM(J-1)=HALFR(I)/V(J-1,N)*VOLUME
JMINI=JMIN-1
JMAXI=JMAX-1
IF(1BURND)4,4,7
IF(1TBRND)EQ.0.0 GO TO 6
IF(1TBRND)EQ.0.0 ).GO TO 6 WAS INSERTED DURING CON-
VERSION TO THE G.E. 635
IF(1BURND-T)6,5,5
DELE=EPEAK*(1-TOLD)/TBRND
TOLD=T
GO TO 7
DELE=0.
IBURND=1
DO 10 JMNHAF,N)
E1=E(JMNHAF,N)-(P(JMNHAF,N)+Q(JMNHAF,NPLHAF))* (V(JMNHAF,NPLUS1)-
1V(JMNHAF,N))
PI=(GAMMA(I)-1.)*E1/V(JMNHAF,NPLUS1)
E(JMNHAF,NPLUS1)=E1-.5*(PI-P(JMNHAF,N))* (V(JMNHAF,NPLUS1)-
1V(JMNHAF,N))

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10 P(JMNHAF,NPLUS1)=(GAMMA(I)-1.)*E(JMNHAF,NPLUS1)/V(JMNHAF,NPLUS1)
   CSQ(JMNHAF)=GAMMA(I)*(GAMMA(I)-1.)*E(JMNHAF,NPLUS1)/ROZERO(I)
   RETURN
END
SUBROUTINE EQST3
   CALCULATE PRESSURE AND ENERGY FOR SOLID ZONES
   COMMON AREA1,AREA2,AREA3,AREA4,AREA5,AREA6,AREA7,AREA8,AREA9,AREA10,
   1 DTMIN,DQ1,DQ2,DS,EZERO,HALFM,HALFR,HALFR2,HALFR3,HALFR4,HALFR5,
   2 KROBNG,EI,FDI,OUTDI,OUTDI2,OUTDI3,OUTDI4,OUTDI5,OUTDI6,OUTDI7,
   3 SIGMAX,TVNEXT,TVOLUME,TVFRREQ,UZERO,UUSQ,TBAR,TBAR2,TVDI1,TVDI2,
   4 VZERO,V,VNEXT,VMIN,VMAX,VMIN2,VMAX2,VMIN3,VMAX3,VMIN4,VMAX4,
   5 COMMON JMAX,INU,I1,INTERJ,I2,INUM,I3,INUM2,I4,INUM3,I5,INUM4,
   6 JPLHAF,JMNHAF,NTV,NCKEKE,NEQST,NJONES,NCYCLE,NSTOP,NMOL,DUMVAR
   7 NPLHAF,NN,NPL3HF,NP1,NP2,NP3,NP4,NP5,NP6,NP7,NP8,NP9,NP10,
   1 DIMENS(3),DLAMDA(200),DTSQ(200),DX4(30),DELX(30),DQ1(30),DQ2(200),
   2 EZERO(30),E(200,2),EINT(30),E(200,2),EINT(30),E(200,2),EINT(30),
   3 HALFM(200),HALFR(30),HYDRAD(200),INT(30),FORCE(30),MACHSQ(200),
   4 NZONES(30),OUTBDY(30),PPLUSQ(200),P(200,2),Q(200,2),ROZERO(30),
   5 SKIN(200),TIGSQ(200),TMINSQ(200),TOVREI(30),THETA(30),UZERO(30),
   6 U(201,2),USQ(201),VZERO(30),V(200,2),VISCOS(200),X(201,2),X1(200),
   7 ZMASS(200),PO(30),AMOL(30),DUMVAR(500,5)
   JMIN1=JMIN-1
   JMAX1=JMAX-1
   DO 10 JMNHAF=JMIN1,JMAX1
   DMU=1./V(JMNHAF,NPLUS1)-1.
   EI=E(JMNHAF,N)
   1 V(JMNHAF,N)={P(JMNHAF,N)+Q(JMNHAF,NPLHAF)}*(V(JMNHAF,NPLUS1)-
   5 DPDMU=21.297.0*(DMU+1.0)**6-3041.4
   IF(P(JMNHAF,NPLUS1)=3042.4*(DMU+1.0)**7-3041.4
   1 P(JMNHAF,NPLUS1)=3000.
   P(JMNHAF,NPLUS1)=E1-5*(P(JMNHAF,NPLUS1)-P(JMNHAF,N))*(V(JMNHAF,
   11 INPLUS1)-V(JMNHAF,N))
   10 CSQ(JMNHAF)=DPDMU/ROZERO(I)
   RETURN
END
SLBROUTINE PVCHNG (PVW,ERR,VEL,PLOAD,GAS,AVEL,ALOAD,AGAS,NU)
DIMENSION GAS(30),AVEL(100),ALOAD(100),AGAS(100)
PVLO=10.
PVI=5000.
DO 20 N=1,NU
IF (AGAS(N).NE.GAS(3)) GO TO 20

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IF (ABS(AVEL(N)-PVW).LT.ERR) GO TO 30
IF (AVEL(N).GT.PVW.AND.AVEL(N).GT.PVHI) GO TO 20
IF (AVEL(N).LT.PVW.AND.AVEL(N).LT.PVLO) GO TO 20
HILOAD=ALOAD(N)
PVHI=AVEL(N)
GO TO 20
40 BALOAD = ALOAD (N)
PVLO = AVEL (N)
20 CONTINUE
IF (PVLO.EQ.10.OR.PVHI.EQ.5000.) GO TO 60
PLOAD=BALOAD+(PVW-PVLO)*(BALOAD-HILOAD)/(PVLO-PVHI)
GO TO 50
30 PLOAD=ALOAD(N)
GO TO 50
60 PLOAD= FLOAD +(PVW-VEL)* 20.
50 GAS(1)=PLOAD
RETURN
END

```

INPUT FORMAT

CARD 1 (4I3, F10.0)

IDATA = 0, STANDARD 18 CARD INPUT
= NAMELIST INPUT OF ALL VARIABLES ON CARDS
IPRNTZ = 0, STANDARD RUN
= 1, PRINT OUT INITIAL DATA ONLY
INTRNSF = 0, USE DISK SCRATCH FILE AND PRINT OUT ONLY LAST PISTON ITERATION
= 1, PRINT OUT ALL PISTON ITERATIONS (HYPERVELOCITY MODEL ONLY)
IPUNCH = 0, NO PUNCHED OUTPUT
= 1, PUNCHED OUTPUT OF MODEL BASE PRESSURE VS TIME
DTSQ(199) FINITE BREAK VALVE OPENING TIME

CARD 2 (20I3)

IMAX = NUMBER OF REGIONS (UP TO SIX)
NDATE1 = MONTH
NDATE2 = DAY
NDATE3 = YEAR
NUMBER = RUN IDENTIFICATION NUMBER
NCHEKE = 0, NO ENERGY CHECK
= 1, ENERGY MONITORED AND PROBLEM STOPPED IF THE TOTAL ENERGY
CHANGES BY MORE THAN 10%
INU = 0, ALL ZONES HAVE ZERO INITIAL VELOCITY
= 1, ALLOWS INITIAL VELOCITY FOR EACH ZONE TO BE READ
JPROJ = MASS POINT NUMBER OF PROJECTILE

CARD 3 (20I3)
NEQST(I) = NUMBER OR INDEX OF EQUATION OF STATE USED IN REGION I

CARD 4 (20I3)
NZONES(I) = NUMBER OF ZONES IN REGION I

CARD 5 (7F10.0)
OUTBDY(I) = DISTANCE IN CM TO OUTER INTERFACE OF REGION I

CARD 6 (7F10.0)
GAMMA(I) = RATION OF SPECIFIC HEATS FOR REGION I

CARD 7 (7F10.0)
CQSX4(I) = CONSTANT USED IN ARTIFICIAL VISCOSITY COMPUTATION
(GOOD VALUES ARE 4.0 FOR GAS REGION, 9.0 FOR SOLID REGION)

CARD 8 (7F10.0)
AREA1 = AREA IN SQ CM OF FIRST CONSTANT AREA SECTION (PROGRAM ALLOWS UP TO
THREE DIFFERENT CONSTANT AREA SECTIONS AND ONE TAPERED SECTION
BETWEEN THE SECOND AND THIRD CONSTANT AREA SECTIONS)
AREA2 = AREA IN SQ CM OF SECOND CONSTANT AREA SECTION
AREA3 = AREA IN SQ CM OF THIRD CONSTANT AREA SECTION
PCON1 = POSITION IN CM WHERE FIRST AREA CHANGE OCCURS
SHPR = PROJECTILE RELEASE PRESSURE IN BARS
EMPROJ = MASS OF PROJECTILE IN GRAMS

OUTDT1 = DELTA T FOR PRINTING UP TO TIME TMAX1
TMAX1 = MILLISECS
OUTDT2 = DELTA T FOR PRINTING UP TO TIME TMAX2
TMAX2 = MILLISECS
XSTOP = POSITION IN CM THAT WHEN THE INTERFACE JSTOP REACHES IT,
THE PROBLEM IS TERMINATED

CARD 9 (7F10.0) REQUIRED ONLY IF INU = 1
UZERO(I) = INITIAL VELOCITY FOR EACH ZONE

CARD 10 (7F10.0)
PCON = POSITION IN CM WHERE THIRD AREA CHANGE OCCURS
SLOPE = SLOPE OF CONSTANT TAPERED SECTION
RADIUS = RADIUS IN CM OF THE CONSTANT AREA SECTION TO THE RIGHT
OF THE TAPERED SECTION

CARD 11 (4F10.0I4)
CALPGM = CALORIES PERGRAM OF POWER
TBURND = TIME TO BURN POWDER
GMSPDR = GRAMS OF POWDER
GASPRS = INITIAL GAS PRESSURE IN POWDER REGION
IHEL = 0 (NOT APPLICABLE TO GUN PROJECT)

CARD 12 (7F10.0)
 IPOX = 0 ALL PLOTS, ALL PRESSURE POINTS (PLOT ROUTINE MUST BE INCLUDED)
 = 1 ALL PLOTS, NO PRESSURE POINTS
 = 5 NO PLOTS, NO PRESSURE POINTS
 = 6 ONLY PRESSURE POINTS
 NPOX = NUMBER OF PRESSURE POINTS (UP TO FIVE)
 XPO(I) = X POSITION IN CM OF PRESSURE POINT I

CARD 13 (7F10.0) HYPERVELOCITY MODEL LAUNCHER PARAMETERS, (NOT APPLICABLE
 TO GUN PROJECT)
 XPV1 = X POSITION IN CM OF FIRST MEASUREMENT POINT OF PISTON VELOCITY
 XPV2 = X POSITION IN CM OF SECOND MEASUREMENT POINT OF PISTON VELOCITY
 PVERR = PISTON VELOCITY ERROR IN FT PER SEC
 PVWANT = DESIRED PISTON VELOCITY IN FT PER SEC

CARD 14 (E10.0, 3F10.0)
 R = 8317E 08 GAS CONSTANT
 EMPIST = MASS OF FIRST PISTON SECTION (HYPERVELOCITY MODEL LAUNCHER ONLY)
 FRAC = 1.0
 EMLEAD = MASS OF SECOND PISTON SECTION (HYPERVELOCITY MODEL LAUNCHER)

CARD 15 (7F10.0)
 PO(I) = INITIAL PRESSURE IN PSI IN REGION I

CARD 16 (7F10.0)
 TO(I) = INITIAL TEMPERATURE IN DEGREES KELVIN IN REGION I

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APPLICATION OF HOLOGRAPHIC INTERFEROMETRY TO THE INTERIOR BALLI--ETC(U)
SEP 76 R L MONTGOMERY

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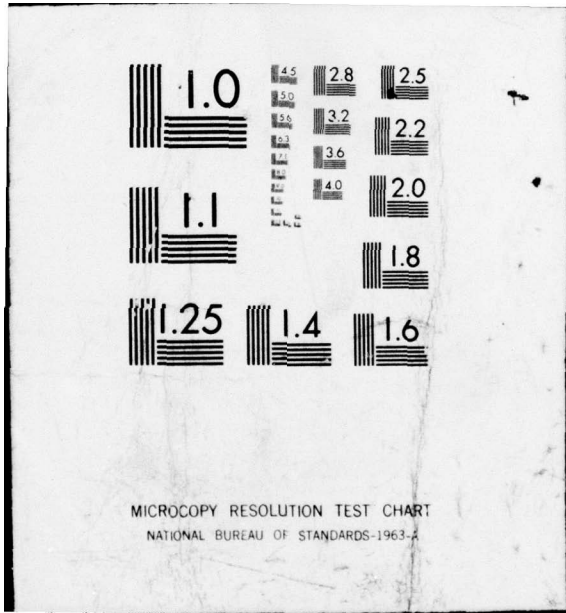
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CARD 17 (7F10.0)
AMOL(I) = MOLECULAR WEIGHT OF MATERIAL IN REGION I

CARD 18 (I3)
ILASTK = 0, STOP
 = 1, CONTINUE FOR NEW RUN

LIST OF REFERENCES

1. Corner, J., Theory of the Interior Ballistics of Guns, Wiley and Sons, 1950.
2. Gough, P. S., Fundamental Investigations of the Interior Ballistics of Guns, North Troy, Vermont, 1974.
3. Smith, H. M., Principles of Holography, Wiley and Sons, 1969.
4. Collier, R., Burckhardt, C. B., and Lin, L. H., Optical Holography, Academic Press, New York, 1971.
5. Naval Ordnance Laboratory Technical Report 62-87, Ballistics Research Report 67, 1963, Computer Analysis of Two-Stage Hypervelocity Model Launchers, by R. Piacesi, D. F. Gates, and A. E. Seigel.
6. Richtmyer, R. D., Difference Methods for Initial Value Problems, Interscience Publishers, Inc., New York, 1957.
7. VanNeumann, I., and Richtmyer, R. D., "A Method for Numerical Calculation of Hydrodynamic Shocks," Journal of Applied Physics, V. 21, P. 232, 1950.
8. Bettinger, R. G., Application of Holographic Interferometry to the Exterior Ballistic Flow Field in the Muzzle Environment of a Twenty Millimeter Cannon, Thesis, Naval Postgraduate School, 1975.
9. Richtmyer, R. D., Difference Methods for Initial Value Problems, Interscience Publishers, Inc., New York, 1957.
10. Hunt, F. R. W., Internal Ballistics, Philosophical Library, Inc., 1951.

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