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SOFT RECOVERY TESTS OF A 155-mm CANNON
LAUNCHED GUIDED PROJECTILE WARHEAD, TYPE T

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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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instrumented with a FM/FM telemetry system to measure base pressure, projectile acceleration, and strains on the inner wall of the warhead.

Three instrumented, CLGP-warhead, test projectiles were fired from a 155-mm, M185 Howitzer tube using an M4A2, Zone 7, Propelling Charge. Telemetry data were received from all three and they were successfully recovered in the LCSRS.

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I. INTRODUCTION

With the design and construction of the Ballistic Research Laboratory (BRL) Large Caliber Soft Recovery System¹ (LCSRS), a useful test apparatus is available to support various research projects. The first task that employed the LCSRS was testing the launch survivability of a Type T, 155-mm Cannon Launched Guided Projectile² (CLGP) warhead. The warhead body was fitted with an appropriate nose, base, slip band, and bourrelet to make it compatible both for launch from a 155-mm, M185 Howitzer tube and recovery in the LCSRS. The purpose of the test was to expose the warhead to the in-tube environment of an actual gun launch, soft-recover the projectile, and disassemble the projectile, so post firing diagnostics and structural tests could be performed on the warhead.

The projectile was also instrumented with a telemetry system for the continuous measurement of physical parameters on-board the projectile during the propulsion phase of the launch trajectory. These experimental data were needed to define the launch environment and to compare with the results derived from a finite element stress analysis of the warhead.

II. DESCRIPTION OF THE LARGE CALIBER SOFT RECOVERY SYSTEM

A photograph of the LCSRS is shown as Figure 1. A schematic showing the principle of operation is presented as Figure 2. Soft recovery of the projectile is achieved by attaching a water scoop to the test projectile and firing the projectile into a water trough inclined at a small angle. This presents an ever-increasing depth of water to the advancing projectile. The impulse of the projectile is converted into the momentum of the water ejected forward by the scoop on impact. The 60-meter length of the system is sufficient to stop the projectile with a maximum deceleration less than 10% of the maximum launch acceleration. The theoretical projectile deceleration in the LCSRS is presented as Figure 3 for the CLGP projectile weight (51.9 kg) and a trough inclination angle of 1.20 mils. Predicted launch velocity was 533 metre per second. The drag equation and computer code used to calculate this deceleration are given in Reference 1.

III. DESCRIPTION OF THE PROJECTILE

A diagram indicating the location of the various parts of the test projectile is shown in Figure 4. A photograph of the projectile, broken

¹E. J. Halcin and J. A. Pratt, "Design of a Large Caliber Soft Recovery System for the Ballistic Research Laboratories," Ballistic Research Laboratory Contractor Report No. 308, Honeywell Inc., August 1976. (AD #B013626L)

²C. R. Hargraves, "Metallurgical Control of Fragmentation, Phase II," Ballistic Research Laboratory Contractor Report No. 350, Honeywell, Inc., September 1977. (AD #B022333L)



Figure 1. Large Caliber Soft Recovery System

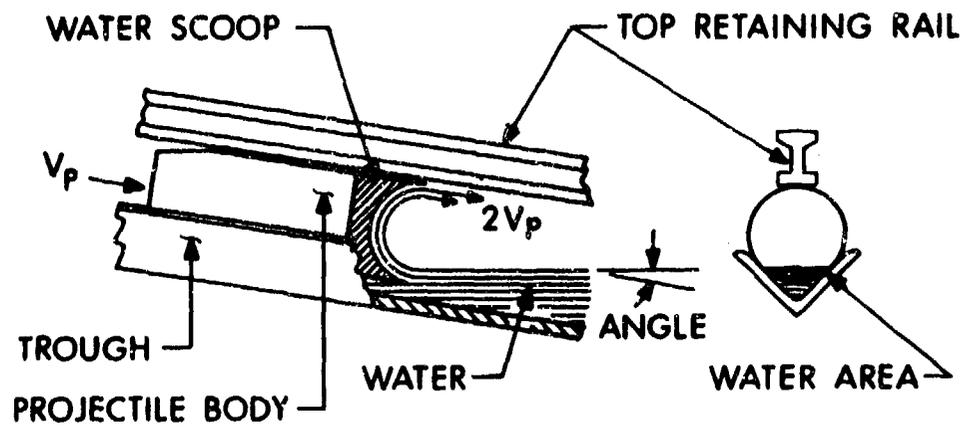


Figure 2. Large Caliber Soft Recovery System, Principle of Operation

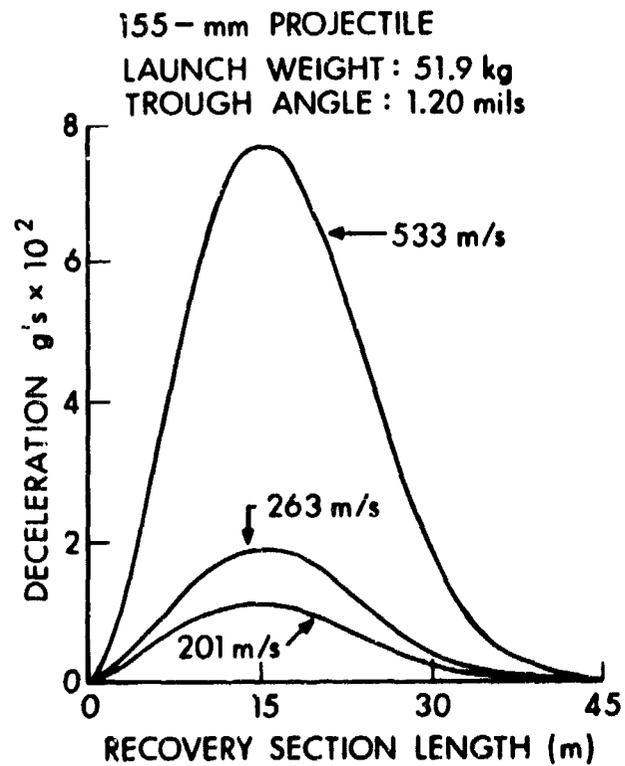
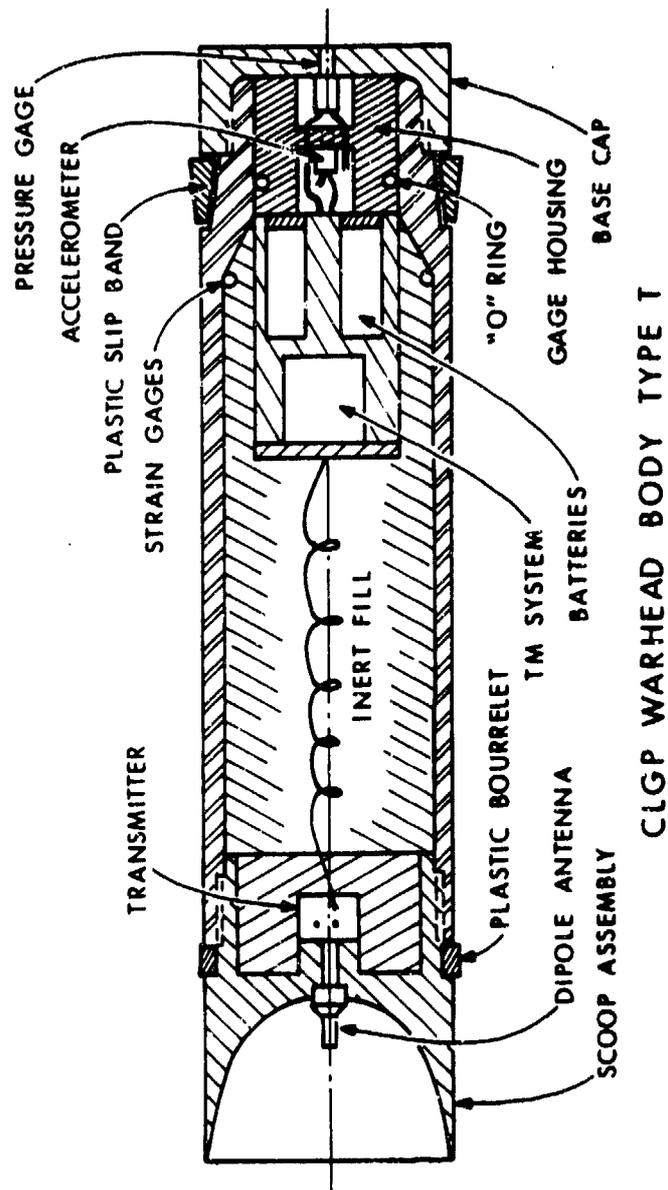


Figure 3. Large Caliber Soft Recovery System, Deceleration Profiles



CLGP WARHEAD BODY TYPE T

Figure 4. CLGP Warhead, Test Projectile

down into its component parts, is shown in Figure 5 and an end-on view of the assembled projectile, looking into the scoop with an antenna mounted, is shown in Figure 6. The CLGP warhead body was unmodified for the projectile system shown. All mating parts were made to conform to the warhead body.

A. Water Scoop

The water scoop was designed, as per LCSRS specification, to have the necessary interior contour to eject the impacted water forward. The water entered onto a conical surface of revolution that blended into a spherical surface of revolution. The antenna and radio frequency transmitter, for the telemetry system, were located in the scoop structure (Figure 7). The radiating elements and feed cable of the antenna that protruded into the water path were housed in a phenolic fiberglass member. Upon impact with the water, this structure was designed to break away so as not to interfere with the water flow over the scoop surface.

The scoop was attached to the warhead body by a threaded section. The threads were compatible with the existing threads on the forward end of the CLGP warhead body. A surface was provided on the scoop to install a plastic bourrelet. When assembled, the bourrelet was contained between the nose and the warhead (Figures 5 and 6).

B. Base Structure

The base structure (Figure 5) was designed to prevent the propelling gases from entering the warhead and also to provide a housing for transducers and the telemetry electronics. It was attached to the warhead by an existing threaded section on the warhead. A plastic slip band was fitted on an existing contour of the warhead and when the projectile was assembled, the plastic slip band was contained between the warhead and the base structure.

C. Projectile Assembly

Upon final assembly of the components, the projectile was filled with an epoxy. The epoxy was used to simulate the high explosive normally carried in the warhead body and it also provided support for wires that connected the various components of the telemetry system. Filling the projectile was accomplished through a threaded orifice in the scoop (Figure 6). A vacuum system was used to lower the pressure inside the warhead so the epoxy would flow easily into the cavity and fill all voids. After filling, the orifice was closed with a pipe plug, the protruding material machined off, and an epoxy was used to fill around the plug and match the contour of the scoop surface.

After launch and recovery, the projectile was disassembled by removing the water scoop assembly and base cap. The projectile was then put into a cold chamber at -10°C for 24 hours. The difference in the thermal

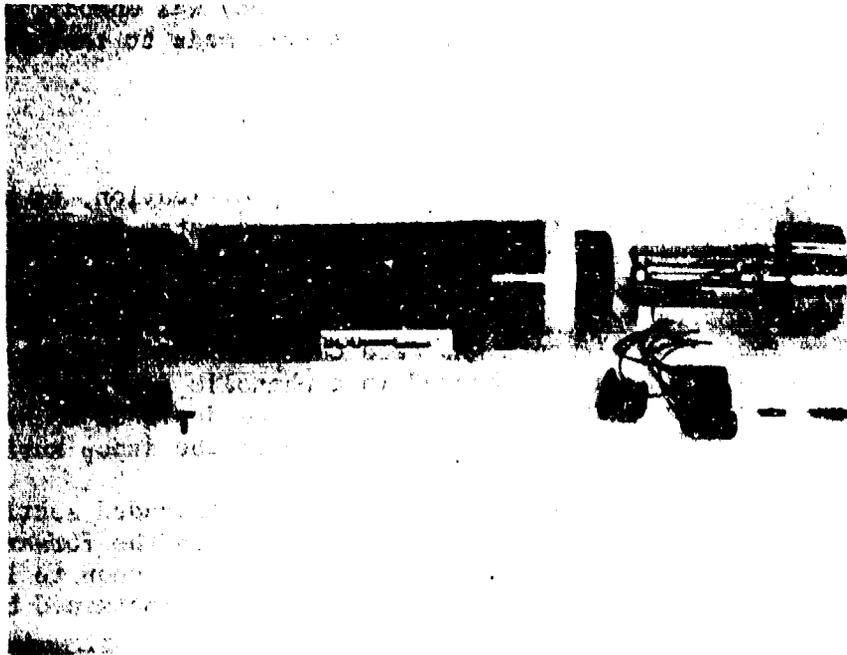


Figure 5. CLGP Warhead, Test Projectile Components



Figure 6. CLGP Warhead, Assembled Projectile

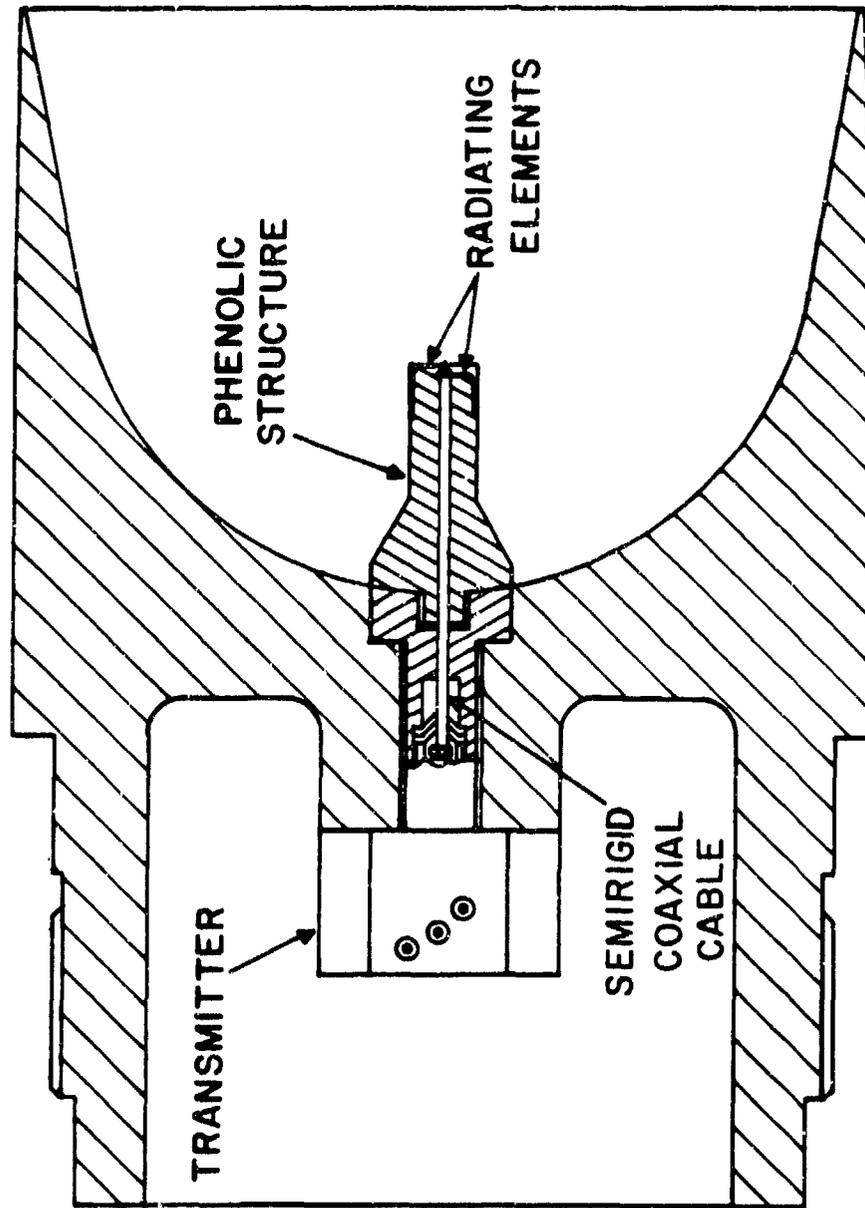


Figure 7. Water Scoop

expansions of the warhead and the epoxy caused them to separate and the epoxy was easily removed from the warhead.

IV. DESCRIPTION OF THE TELEMETRY TRANSMITTING SYSTEM

The telemetry system³ was designed to provide continuous measurements of four performance parameters on-board the projectile during the in-bore phase of its launch trajectory: projectile base pressure, linear acceleration, and strain at two locations on the inner wall of the warhead. The strain measurements were made at points under and between zones of varying metallic hardness² (Figure 4).

Instrumentation for the telemetry system consisted of a dipole antenna, S-band transmitter, four voltage controlled oscillators (VCOs) and three battery packs. The VCOs were frequency modulated by the voltage analog signals produced by the four transducers. The outputs from the VCOs were summed and used to frequency modulate the transmitter to form a conventional FM/FM system. A block diagram of the transmitting system is shown as Figure 8.

A. Transmitter and Antenna

A Microcom Corp., Model T-4 transmitter (T, Figure 5) with nominal frequency of 2.22 GHz and output power of 20 milliwatts was mounted in the water scoop assembly (Figure 7) to the rear of the antenna lead port. The antenna, designed at BRL, consisted of a phenolic member threaded at the base for mounting in the antenna-transmitter adapter. The base of the antenna-transmitter adapter housed the mating push connector to the transmitter. A semi-rigid coaxial cable, which passed through the long axis of the phenolic structure, was connected to fine wires that formed the dipole radiating elements. These elements were bent to conform to the outside of the phenolic member and ran parallel to its long axis. A small, 100-ohm resistor, connected across the dipole, was used to broadband the antenna.

After assembling the transmitter and antenna in the water scoop and connecting hook-up wires to the transmitter, the warhead cavity, where the transmitter was located, was filled with an epoxy.

B. Voltage Controlled Oscillators

The center frequencies (f_c) of the Omnitek, Inc. VCOs were 128, 192, 256, and 320 kHz with a ± 16 -kHz deviation. The input voltage range for both the pressure transducer and accelerometer modulated

³J. W. Evans, "In-Bore Measurements of Projectile Acceleration and Base Pressure using an S-Band Telemetry System," Ballistic Research Laboratory Memorandum Report No. 2562, December 1975. (AD #B008421L)

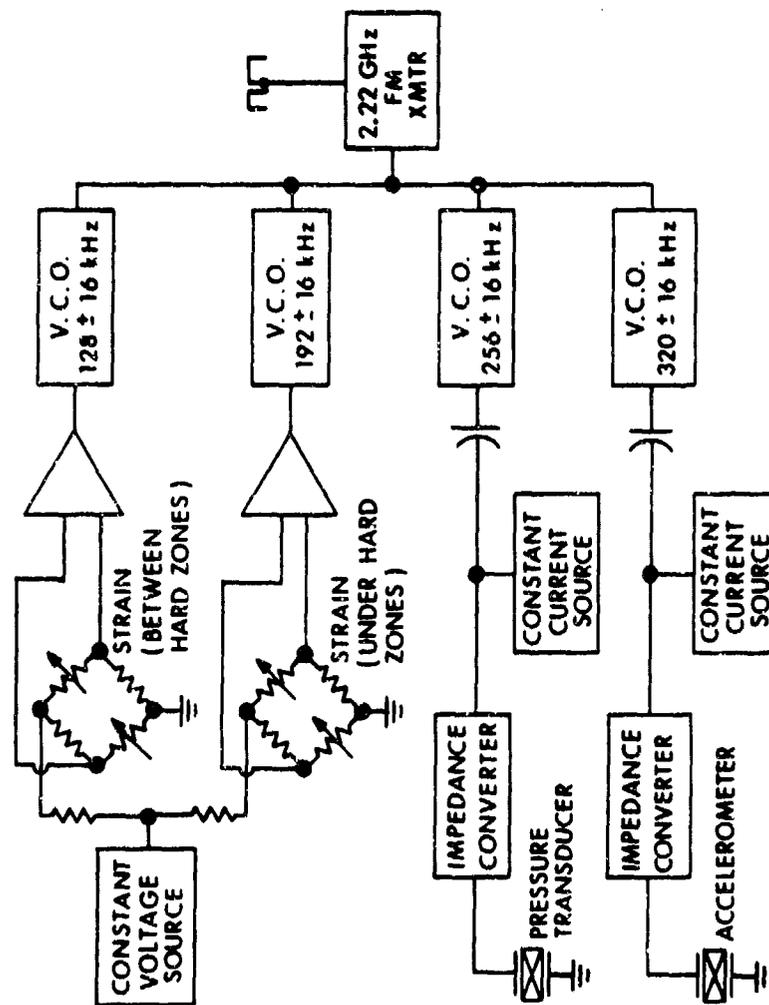


Figure 8. Telemetry Transmitting System, Block Diagram

VCOs was 0 to 5 volts. The VCOs modulated by the strain transducers had an input range of ± 2.5 volts since both tension and compression were to be measured.

C. Piezoelectric Transducers

The pressure transducer and accelerometer, shown in Figure 9 (P and A), were PCB Piezotronics, Inc., Models 109A⁴ and 305M⁵, respectively. Each contained a P-channel, Mosfet, source follower⁶ within its housing. These source followers functioned as impedance converters and provided a nominal 100-ohm output impedance. Excitation for these circuits was provided by a constant current source and the analog output signal was capacitive coupled to the VCO. Full scale output for these units was 5 volts. The circuit diagrams for the piezoelectric transducers and the excitation circuit are shown as Figure 10.

The pressure transducer contained a very rigid, acceleration-compensated, quartz element coupled to the source follower. This transducer was mounted in the base structure (Figure 4) with the gage diaphragm exposed to the propellant gases via a short silicone grease column.

The accelerometer contained a seismic-mass-loaded quartz element coupled to the source follower. This transducer was mounted on the projectile long axis in the base structure of the projectile in tandem with and forward of the pressure transducer.

D. Strain Measurements

The strain measurements were made with foil-type, resistive, strain gages cemented to the inner wall of the warhead body and connected in a bridge network. The strain gages formed two active arms of the bridge and were located 180 degrees apart on the body surface to compensate for bending moments in the body. The orientation of the gages were such that they responded to the axial component of strain in the body. The inactive arms of the bridge consisted of similar strain gages which were isolated from the body strain by implanting them in the base housing. The use of the same type of strain gages throughout the bridge network minimized

⁴"Model 109A Pressure Transducer Instruction Manual," PCB Piezotronics, Inc., Buffalo, NY 14225.

⁵"Model 305M Accelerometer Instruction Manual," PCB Piezotronics, Inc., Buffalo, NY 14225.

⁶PCB Piezotronics, Inc., General Guide to ICP Instrumentation, Pamphlet G-0001, Buffalo, NY.

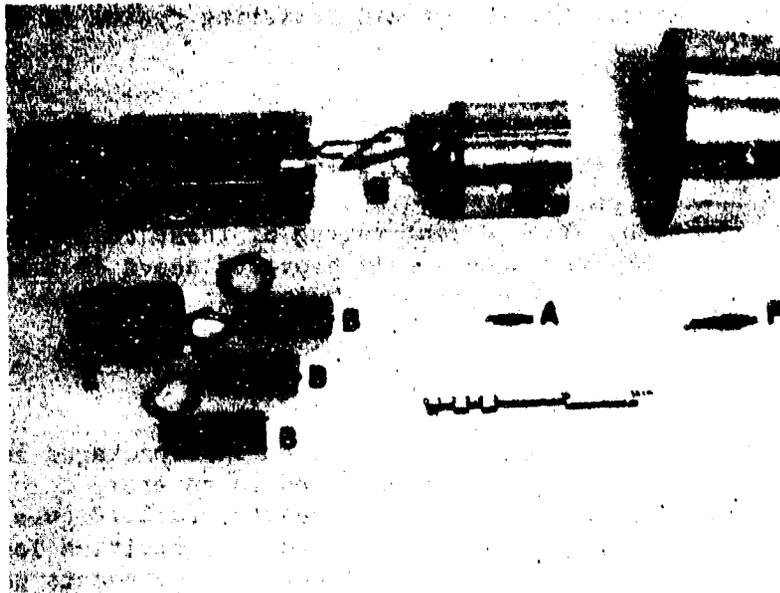


Figure 9. Base Structure Components

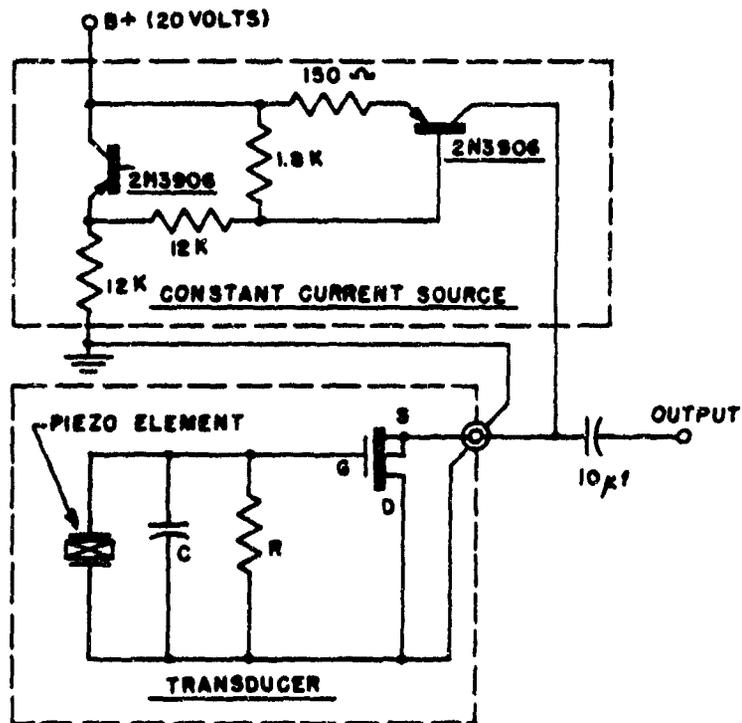


Figure 10. Piezoelectric Transducer and Power Supply

thermal drift. Bridges for both strain circuits were excited by the same constant-voltage source. The differential, analog, voltage output was amplified by an Omnitek, Inc. amplifier to make it compatible with the VCO. A circuit diagram for the strain measuring system is shown as Figure 11.

E. Power Supply

The power supply for the transmitting system consisted of three, series-connected battery packs (B, Figure 9) made up of six rechargeable, nickel-cadmium cells each. The current rating of these cells was 250 milliampere-hours at a 10-hour rate. This provided about 45 minutes of operation for the transmitting system. Output voltage under load was a nominal 22-20 volts.

F. Packaging

The electronics for the transmitting system were packaged in a cylindrical module (E, Figure 9) and encapsulated in an epoxy compound. The module was mounted in a cavity in the base structure (Figure 4). The battery packs were inserted in three cylindrical cavities located 120 degrees apart in the base structure. After all components were assembled and connected, all voids within the base structure were filled with an epoxy compound.

V. CALIBRATION OF THE TELEMETRY TRANSMITTING SYSTEM

The information transmitted by an FM/PM telemetry system is contained in the frequency of the subcarriers⁷. Therefore, it was necessary to define the magnitude of the physical parameter being measured in terms of the output frequency of the VCO. This was accomplished by convolution of the transducer calibration factor with the transfer function of the VCO.

A. Pressure Channel

The pressure transducers were calibrated in a dead weight calibration facility. They were subjected to seven static pressure levels and the output voltages recorded. The set of points resulting from this calibration was used to determine the least squares parabola with pressure as the dependent variable and output voltage as the independent variable ($P = a + bV + cV^2$). The VCO used in the pressure data channel was calibrated by impressing a series of voltage levels on the input and

⁷M. H. Nichols and L. L. Rauch, *Radio Telemetry*, 2nd ed., John Wiley and Sons, Inc., 1956, pp. 253-267.

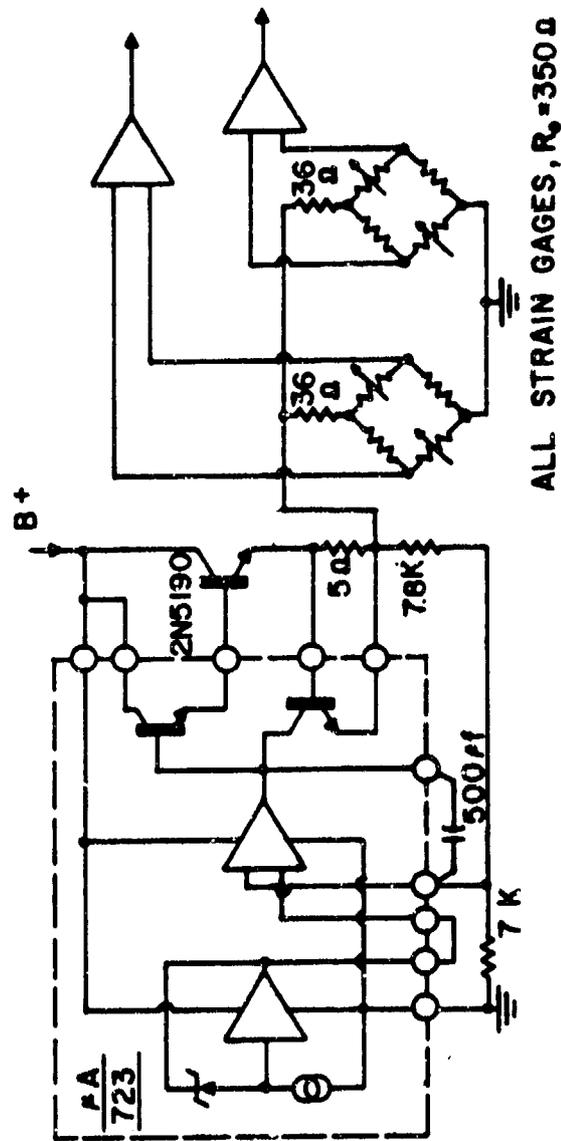


Figure 11. Strain Measuring System

measuring the resulting output frequency. The measured output frequency was normalized to a change in frequency (Δf) where zero represented the VCO lower band edge ($f_c - 16$ kHz). The pressure-voltage relationship was used to calculate a corresponding pressure for the various voltage level inputs to the VCO. This formed a set of points of pressure and Δf that were used to determine the least square parabola with pressure as the dependent variable and Δf as the independent variable ($P = \alpha + \beta\Delta f + \psi\Delta f^2$).

Since the output impedance of the pressure transducer was about 100 ohms and the input impedance of the VCO was about 150 kilohms, the loading factor was negligible. The VCO did not significantly alter the transducer output when they were interfaced. Therefore, the technique of convoluting the transducer calibration and the VCO calibration was valid. The pressure- Δf relationship was used in the data reduction process.

B. Acceleration Channel

The manufacturer's linear calibration factor for the accelerometer was used since an in-house calibration facility was not available. The VCO used in the acceleration data channel was calibrated and normalized similar to the pressure channel. The calibration for the accelerometer and the VCO were convoluted and the least square parabolic fit was determined.

C. Strain Channels

The strain channels were calibrated end-to-end by substituting precision decade resistors for the active arms of the bridge. First, the bridge was balanced with all strain gages connected. Then one active arm was disconnected and the decade resistor box substituted. The bridge was then rebalanced to the previous quiescent point. The other active arm was then substituted in the same manner. When both active arms had been replaced, the two decade resistor boxes were varied by the same increments over the expected range. The VCO frequencies were recorded for each increment. The resistive increments were converted to strain increments using the manufacturer-furnished gage factor. The least squares parabolic fit was then made for the strain- Δf relationship.

VI. DESCRIPTION OF TELEMETRY RECEIVING SYSTEM

A. Radio Frequency Receiving System

The output signals transmitted from the projectile during the in-tube travel were received via a helical antenna located forward and to the left of the muzzle. It was found that precise positioning of the antenna was not critical, except that it be placed outside the area

of extreme muzzle blast effects to prevent damage. Output signals from this antenna were fed into a down converter that translated the nominal 2.22-GHz signal to a nominal 235-MHz signal. This was done to avoid the large attenuation at the 2.22-GHz frequency caused by the 30.5 metres of coaxial cable between the antenna and the receiver. Signal level inputs to the receiver was then at -40 dbm.

B. Data Discriminating System

The data discriminators used in the second detection process had an input bandwidth of 32 kHz and an output low-pass filter bandwidth of 8 kHz. The telemetry data channels were interrupted 350 milliseconds prior to the event to insert a voltage staircase calibration. The amplitude and off-set of the staircase were adjusted to be compatible with the recording device. The discriminator output voltages were correlated with the calibration staircase by adjusting their band-edge voltage outputs. The lower band-edge ($f_c - 16$ kHz) voltage was adjusted to coincide with the staircase baseline and the upper band-edge ($f_c + 16$ kHz) voltage was adjusted to coincide with the staircase top calibration step. These two extremes represented Δf equal to zero and Δf equal to 32 kHz respectively in the transducer least square parabolic fit. The recorded staircase and data from the event represented the VCO frequency excursion with the staircase steps defining the magnitude of the physical parameter being measured. A block diagram of the telemetry receiving system is shown as Figure 12.

VII. ON-TUBE MEASUREMENTS

A. Chamber Pressure

Propelling gas pressures were measured at two locations in the cannon using Kistler 607C piezoelectric pressure transducers. These transducers were located in the spindle face and in the cannon side wall near the projectile base when it was seated. These pressures were used to monitor the charge performance and to correlate with the telemetered base pressure data.

B. Projectile Displacement

A simple, compact, 10-GHz, doppler radar^{8,9} was fabricated to obtain projectile displacement during the in-tube travel. These data were used to

⁸D. C. Vest, J. E. Anders, B. B. Grollman, and B. L. DeMare, "Ballistic Studies with a Microwave Interferometer - Part I," Ballistic Research Laboratory Report No. 968, September 1955. (AD #81617)

⁹D. C. Vest, J. E. Anders, H. C. Smith, B. B. Grollman and T. Kashiwara "Ballistic Studies with a Microwave Interferometer - Part II," Ballistic Research Laboratory Report No. 1008, February 1957. (AD #127631)

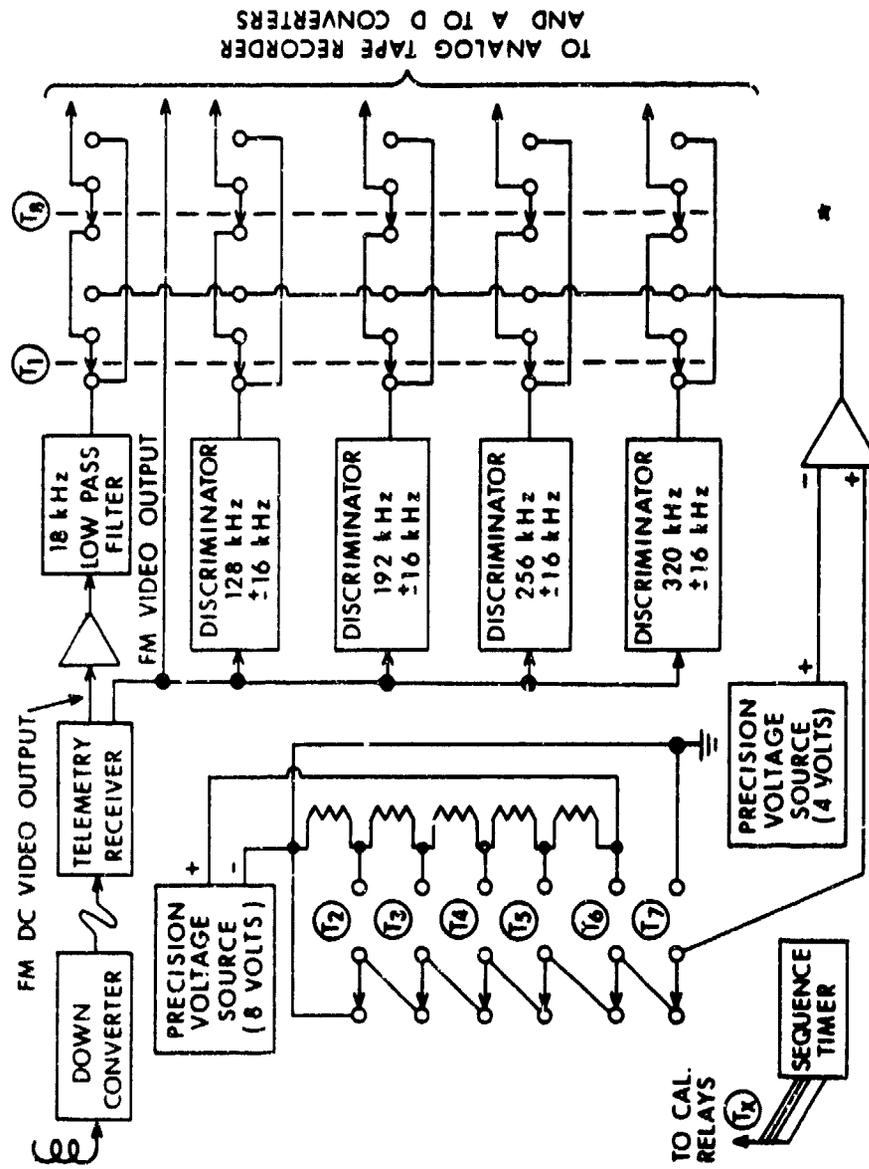


Figure 12. Telemetry Receiving System, Block Diagram

compare with the double integrated, telemetered acceleration data. Since the muzzle of the gun was near the LCSRS, it was not possible to reflect a doppler microwave signal into the gun tube in the conventional manner. Therefore, the radar was configured so it could be concealed within the LCSRS entrance assembly and have an expendable antenna. A simplified block diagram of the doppler radar is presented as Figure 13. The radar was protected from muzzle blast by sand bags and was connected to the antenna by a one-metre long, semi-rigid, coaxial cable.

The antenna, shown as Figure 14, had a circular ground plane and used the coaxial center conductor as the radiating element. Three small screws protruding from the ground plane directed the radiation pattern toward the muzzle. The antenna was mounted about one metre forward of the muzzle and just below the line of fire.

VIII. RECORDING AND DATA REDUCTION

The data from the telemetry system and the on-tube pressures were recorded in real time on an analog-to-digital recorder that was a subsystem of the Ballistic Data Acquisition System (BALDAS). These data were simultaneously recorded on analog, FM, magnetic tape along with the doppler signal. These data, including the calibration staircase, were manipulated, scaled, and converted to engineering units under the control of the BALDAS minicomputer. This system outputted the data in the form of plots on an electrostatic plotter. The data from the doppler radar were reduced by hand reading a chart recorder playback. The doppler radar displacement was entered into the BALDAS system via the terminal keyboard.

IX. RESULTS

Three instrumented, CLGP-warhead, test projectiles were fired from a 155-mm, M185 Howitzer tube using an M4A2, Zone 7, Propelling Charge. All three were successfully recovered in the LCSRS. There was no visible damage or catastrophic structure failures of the CLGP projectiles. The three projectiles were disassembled and the warhead section turned over to the Terminal Ballistic Division, BRL for structural testing.

The telemetry link, with each of the three projectiles, was established at system turn-on, prior to loading the projectile. This link was maintained throughout the loading and ramming process, during a ten-minute warm-up period, and during the in-tube travel. The signal was lost at or near muzzle exit. All voltage controlled oscillators and excitation circuitry functioned properly. After recovery, each projectile was refitted with a new antenna and the system was turned on and evaluated. All measurable parameters (VCO frequencies, transmitter frequencies, battery voltage, and transducer quiescent points) on all three rounds were within the pre-launch specifications.

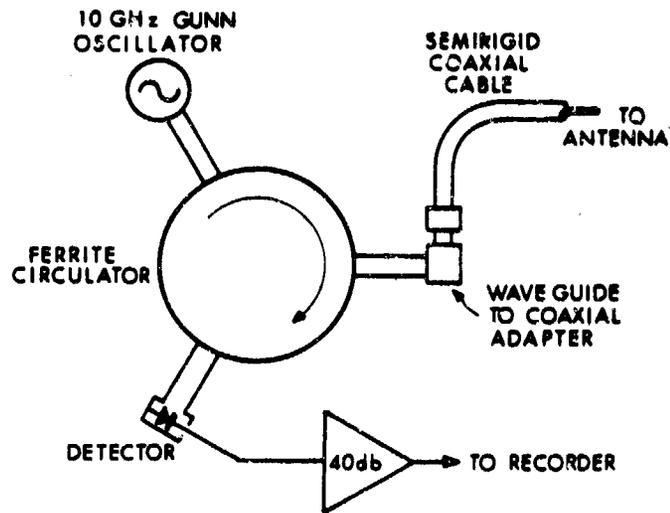


Figure 13. Doppler Radar, Block Diagram

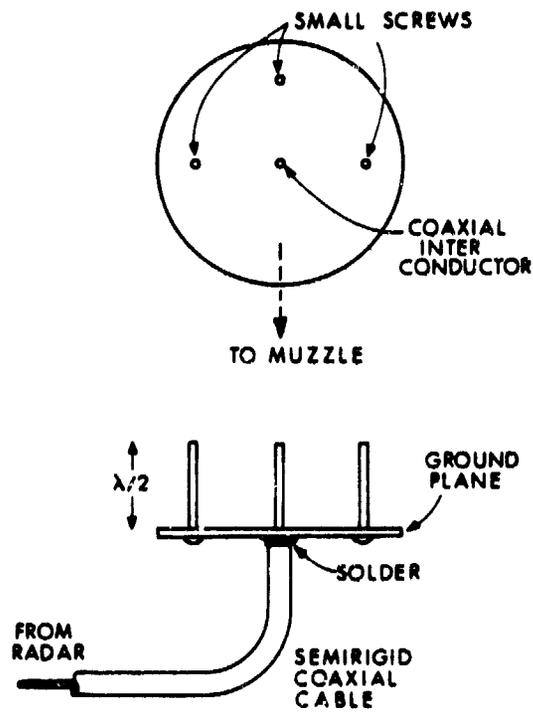


Figure 14. Doppler Radar Antenna

A. Pressure

The telemetered base pressure data, along with the breech and front chamber pressure, are presented for the three rounds as Figures 15, 16, and 17. The base pressure for CLGP Warhead #1 was lower than theoretical calculations predicted. A finite element analysis of the projectile base structure indicated that a binding of the transducer sensing shaft in the mounting hole could occur during pressure loading of the base. For the other two rounds, the mounting hole size was slightly increased. This appeared to correct the problem for CLGP Warhead #2 since the base pressure was near the predicted value. Although the base pressure for CLGP Warhead #3 was near the value of Warhead #2, the difference between the base and spindle pressures was larger than the theoretical prediction. Inaccuracies in either or both these pressure measurements could have caused this discrepancy.

B. Projectile Acceleration

Telemetered, projectile-acceleration data for CLGP Warhead #1 is presented as Figure 18. The negative excursion of this plot is obviously not correct. This was caused by a parasitic transduction-mechanism of the accelerometer mounting structure. Since the accelerometer was mounted on an aluminum structure, the distortion could have been caused by base strain. A steel mounting plate was substituted for the other two rounds, but the same phenomenon occurred on CLGP Warhead #2. To eliminate all solid material that contacted the accelerometer except for the mounting surface, the epoxy that filled the voids in the base structure was not used in the accelerometer cavity on CLGP Warhead #3. This change eliminated the parasitic transduction effect that caused the negative excursion.

The displacement versus time for CLGP Warhead #3, obtained by double integrating the telemetered acceleration, is compared with the displacement obtained from the doppler radar in Figure 19. There is a difference of about 4% in the two sets of data. Since there was no dynamic calibration of the accelerometer for the range it was used, the doppler displacement was believed to be more accurate. The accelerometer data was corrected by multiplying by the ratio of the doppler displacement to the double integrated acceleration. The resulting in-tube trajectory for CLGP Warhead #3 is presented as Figure 20.

C. Body Strain

The strain records for the three CLGP warheads are presented as Figures 21, 22, and 23. From the finite element analysis, all strains appeared to be reasonable. The accuracy of the various strain channels was difficult to determine because the strain patches were not exercised by mechanical loading of the projectile structure after bonding the gages. The nature of the test precluded such a gage calibration.

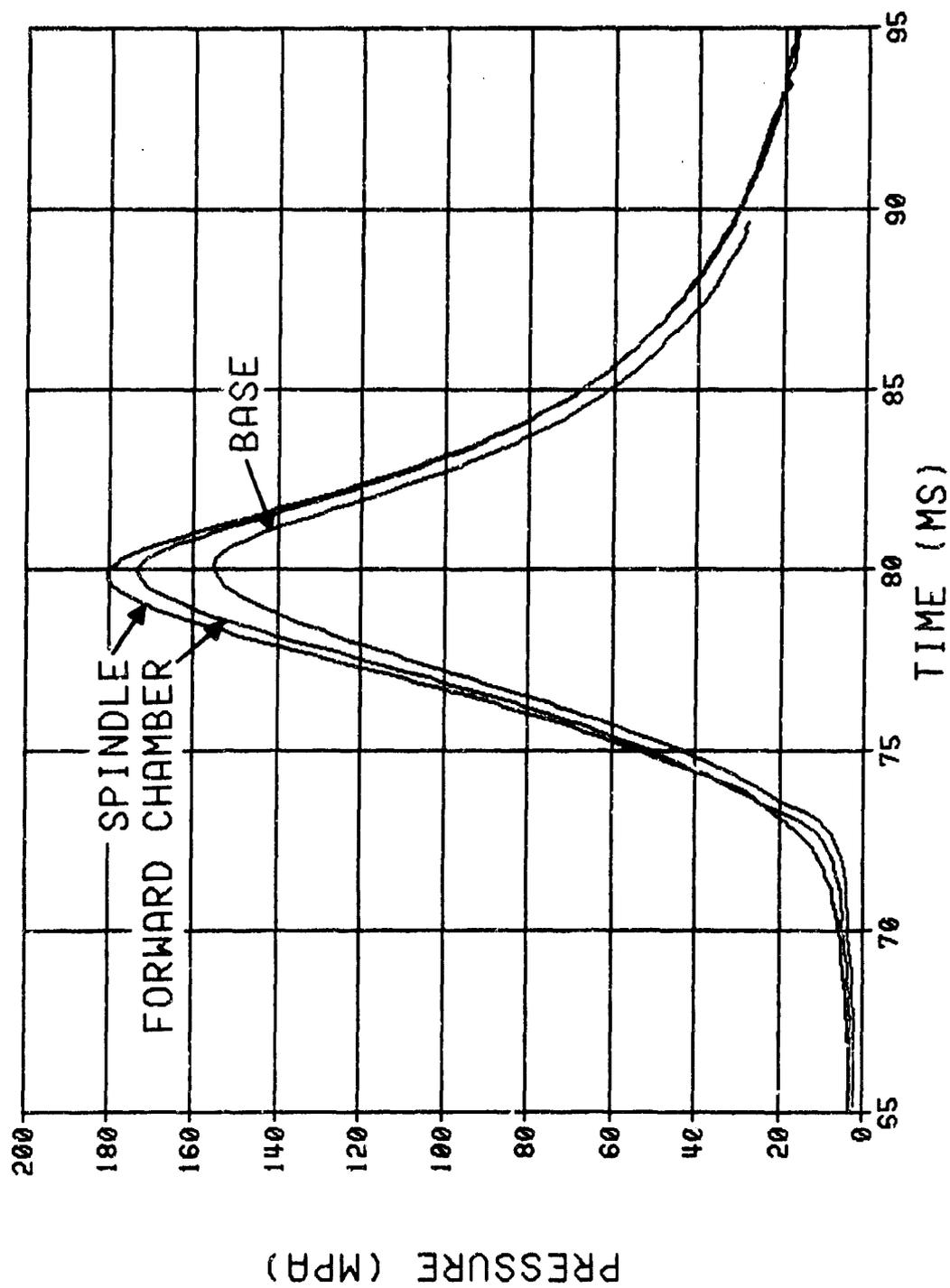


Figure 15. Pressure versus Time, CLGP Warhead #1

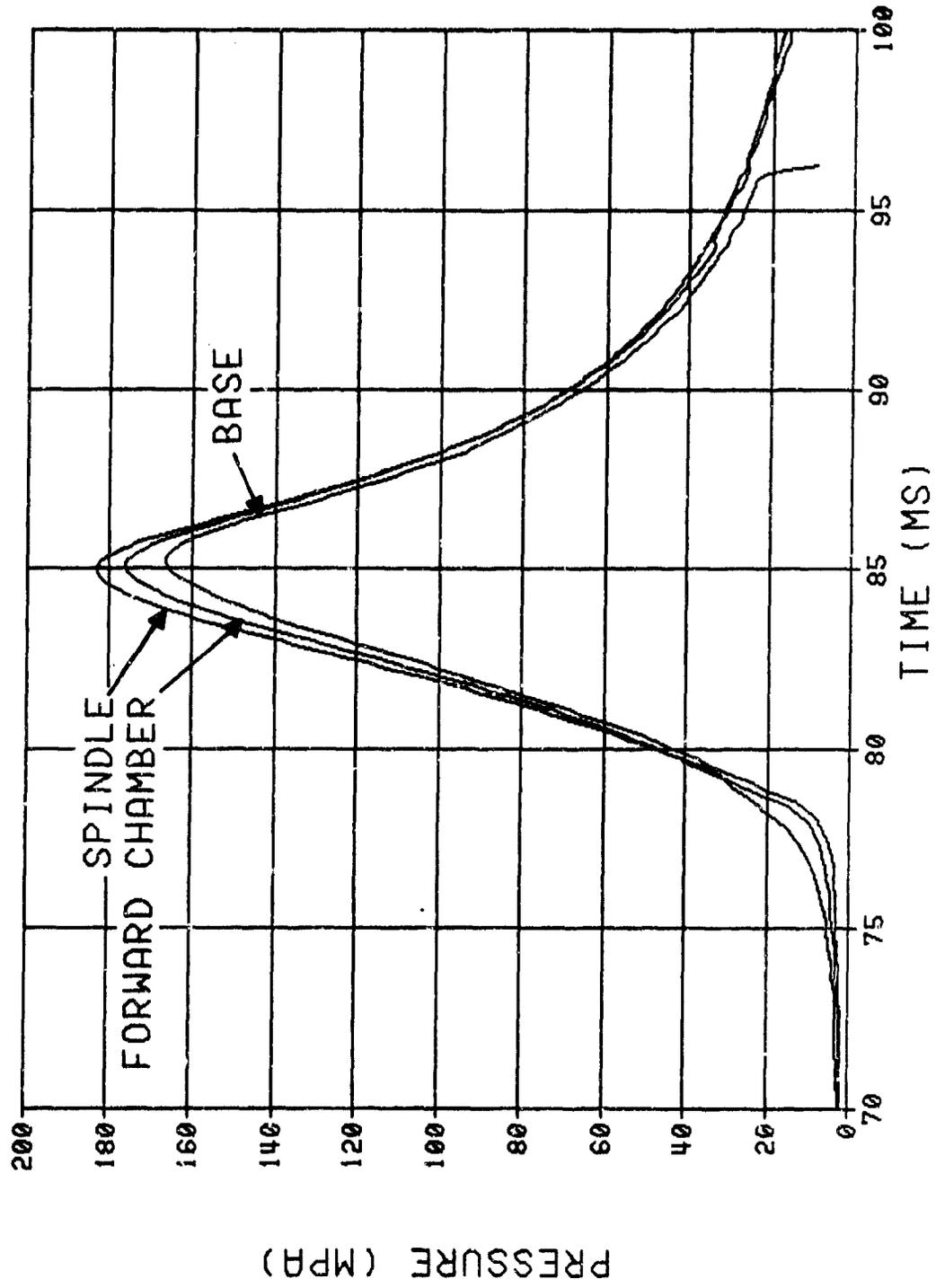


Figure 16. Pressure versus Time, CLGP Warhead #2

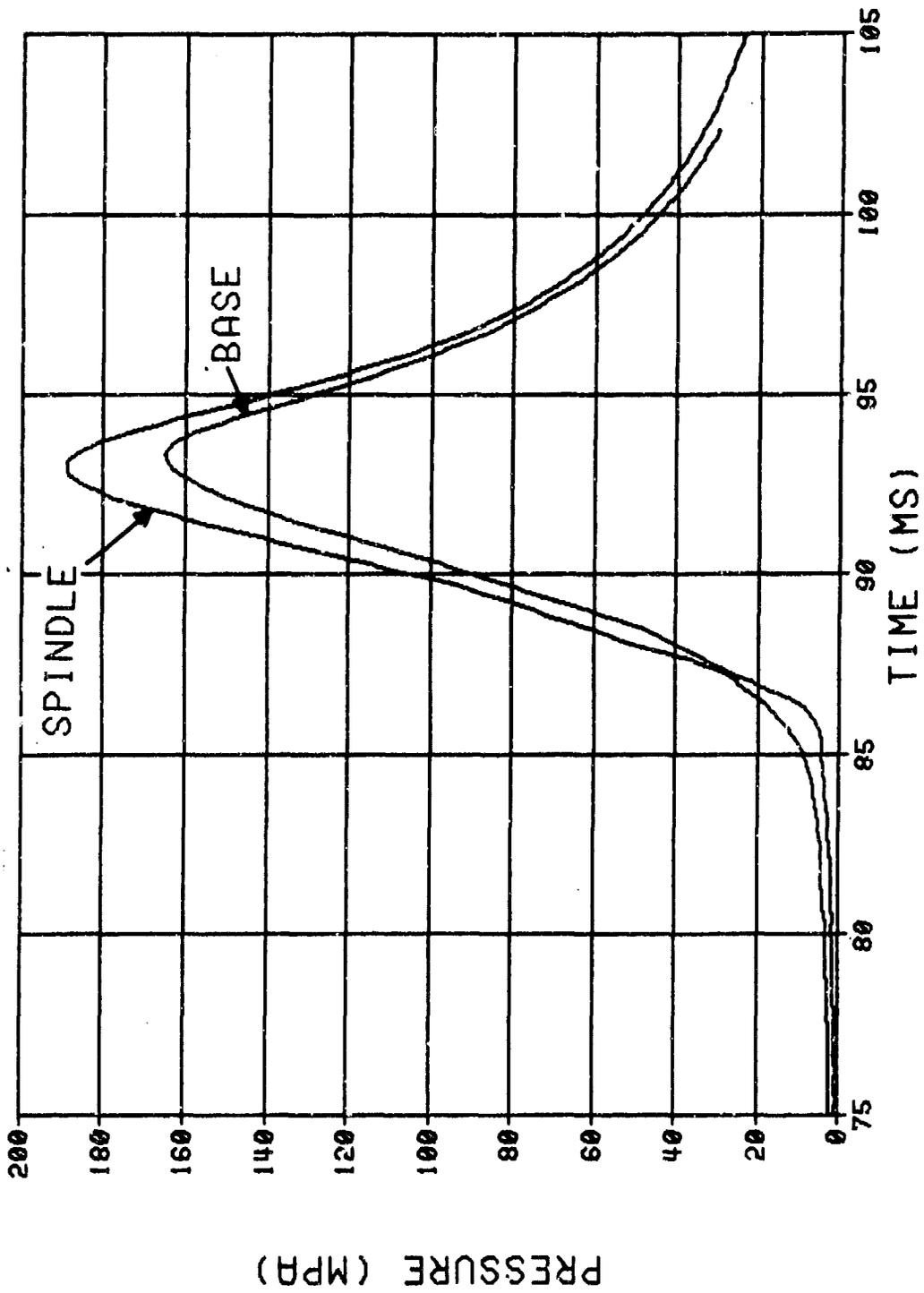


Figure 17. Pressure versus Time, CLGP Warhead #3

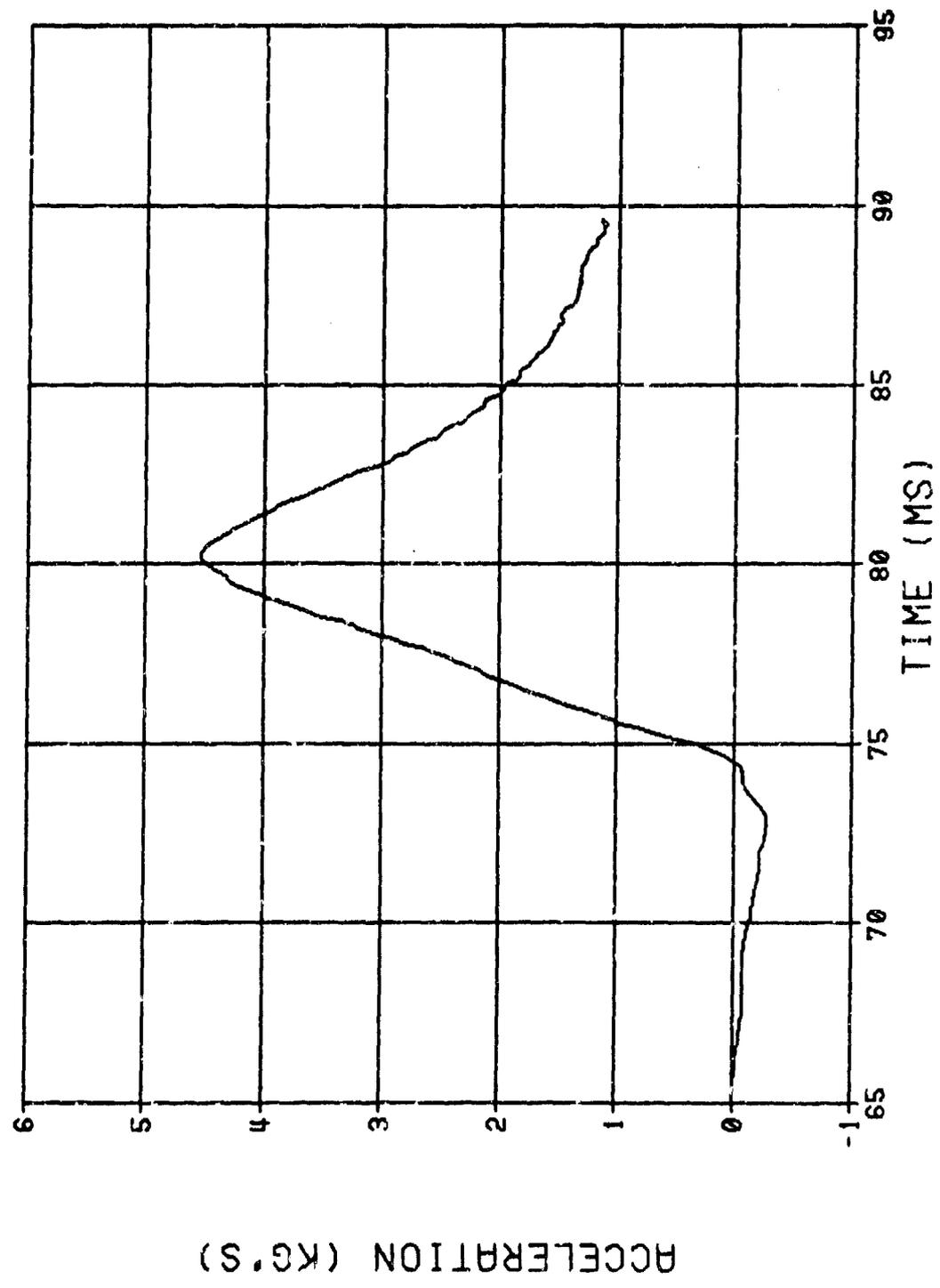


Figure 18. Projectile Acceleration, CLGP Warhead #1

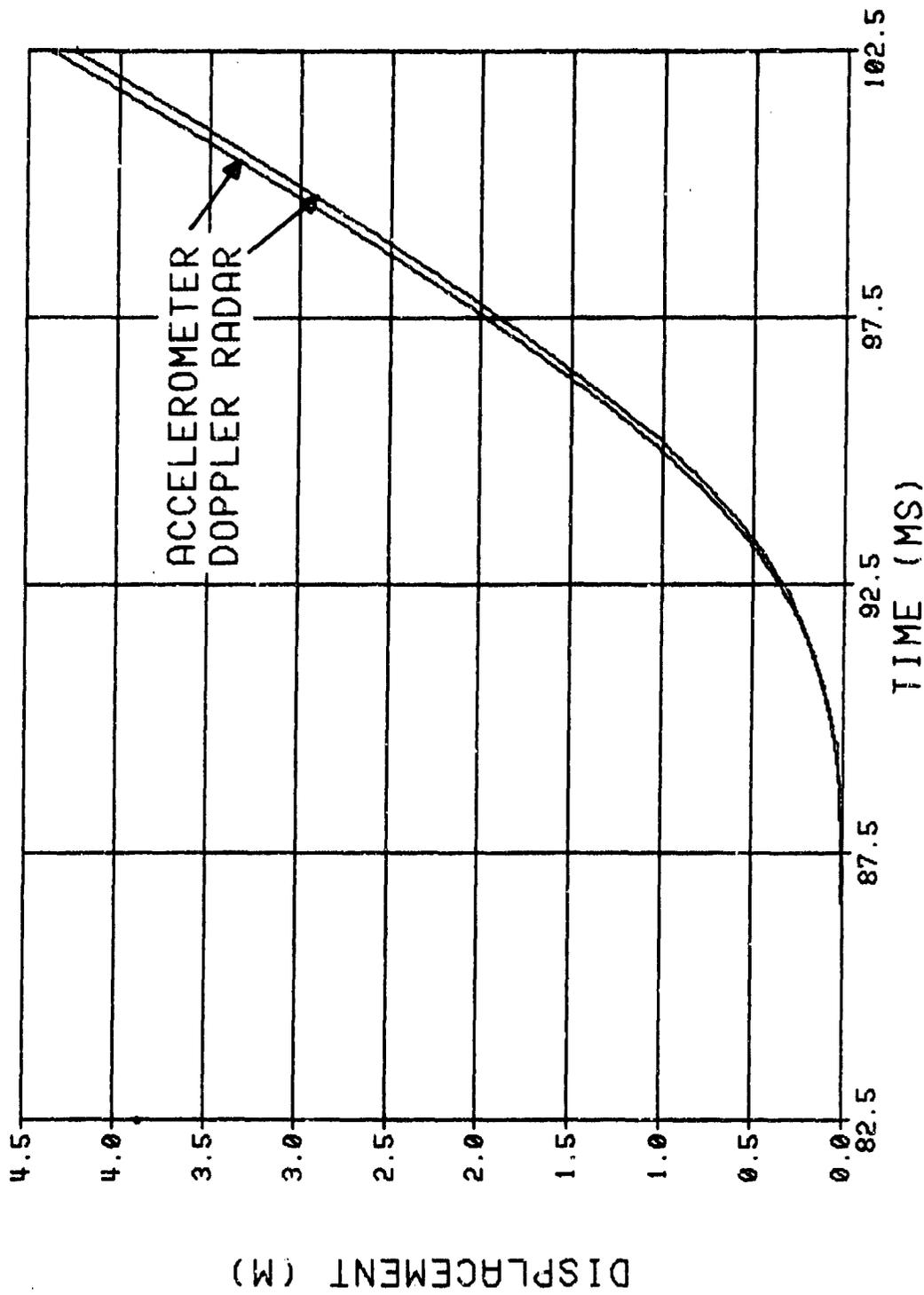


Figure 19. Projectile Displacement versus Time, CLGP Warhead #3

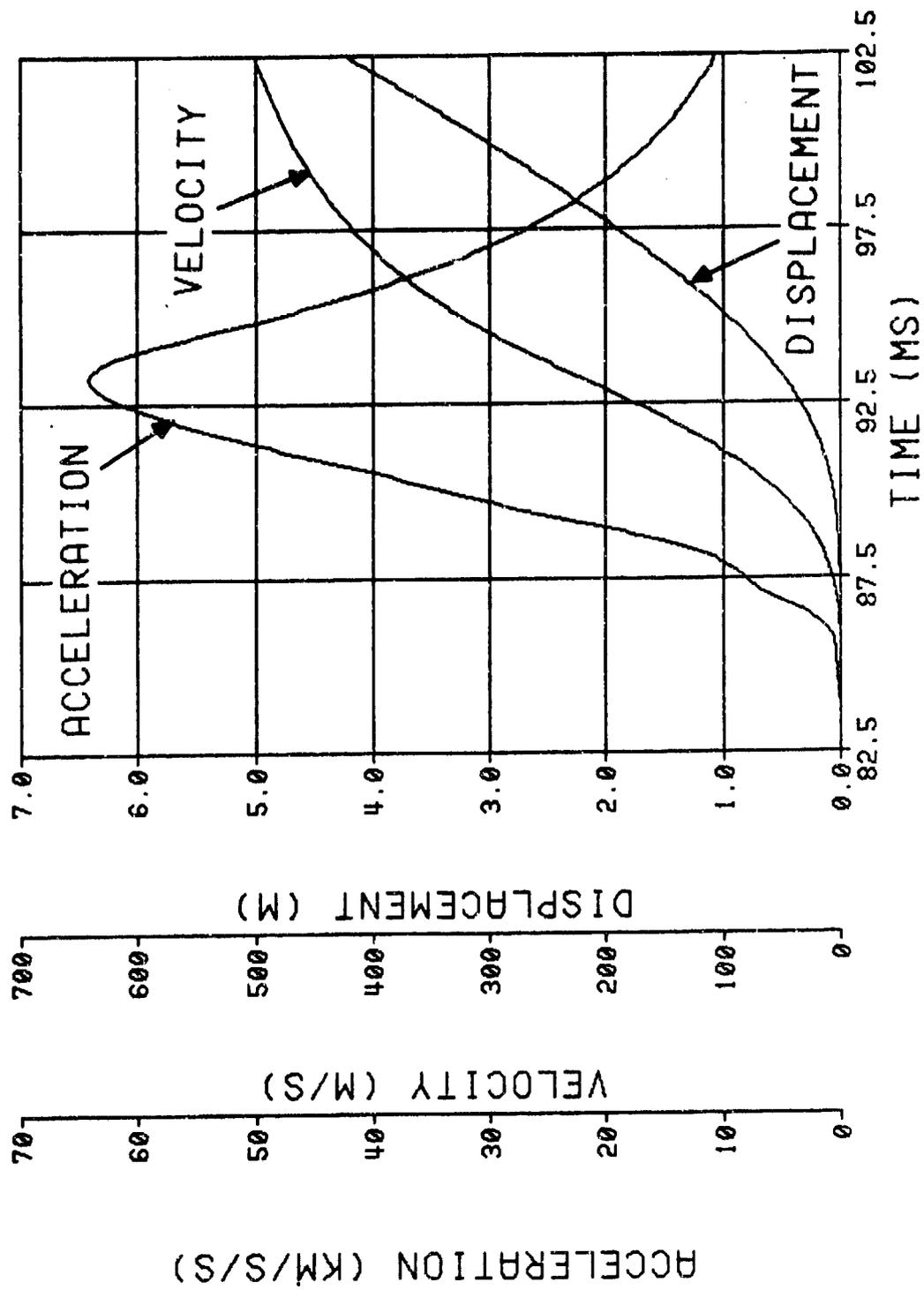


Figure 20. In-Tube Trajectory, CLGP Warhead #3

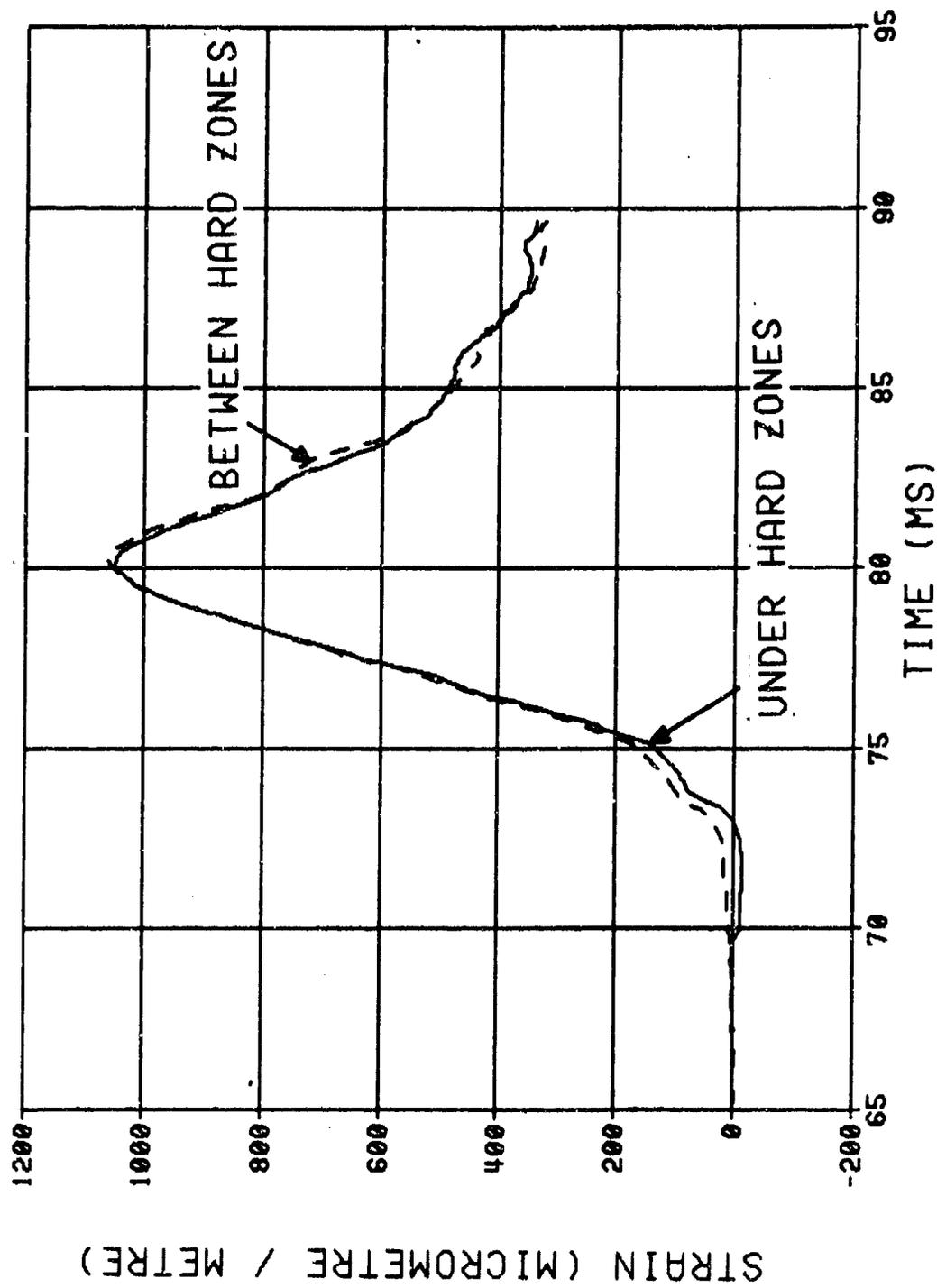


Figure 21. Strain versus Time, CLGP Warhead #1

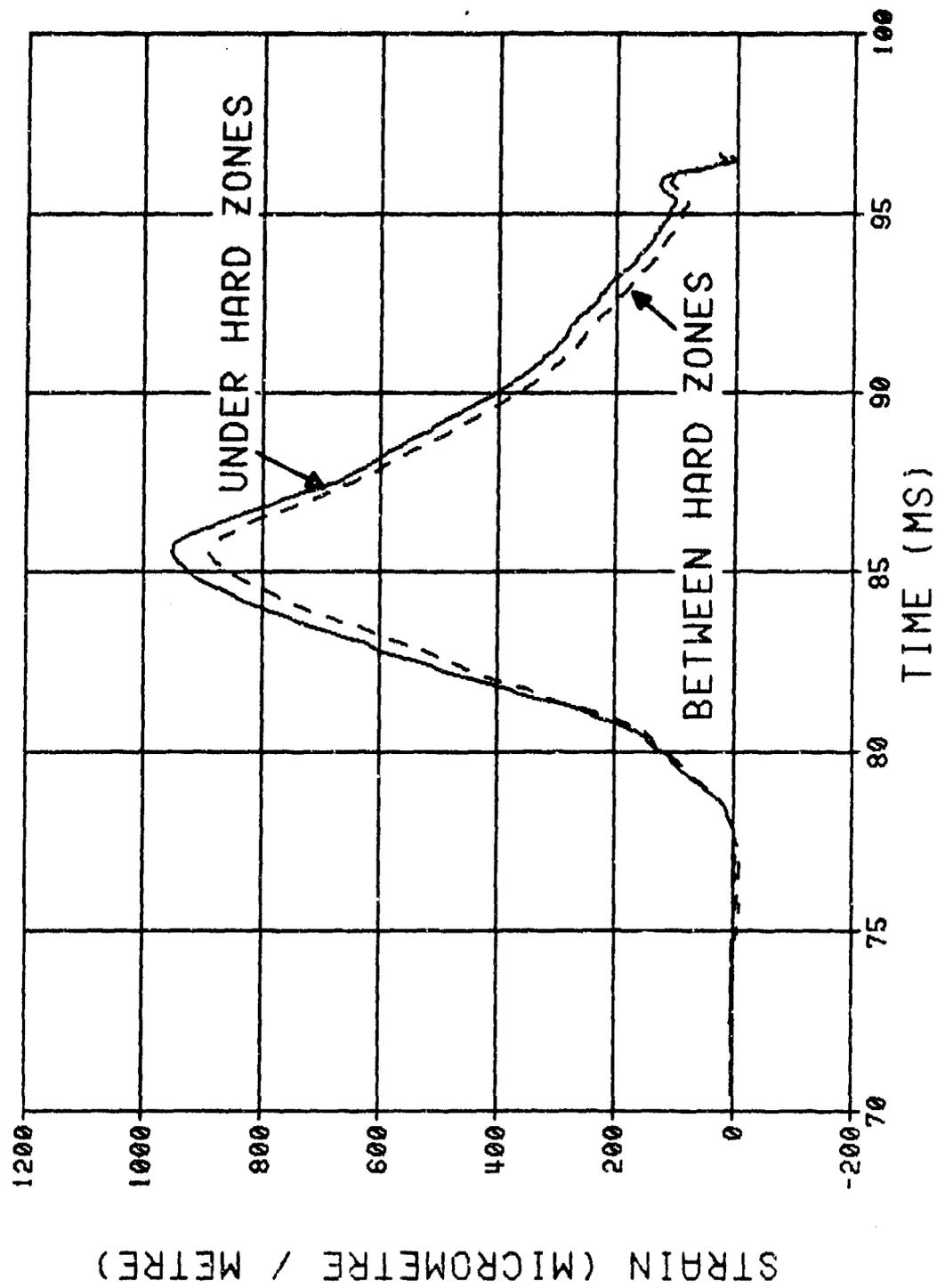


Figure 22. Strain versus Time, CLGP Warhead #2

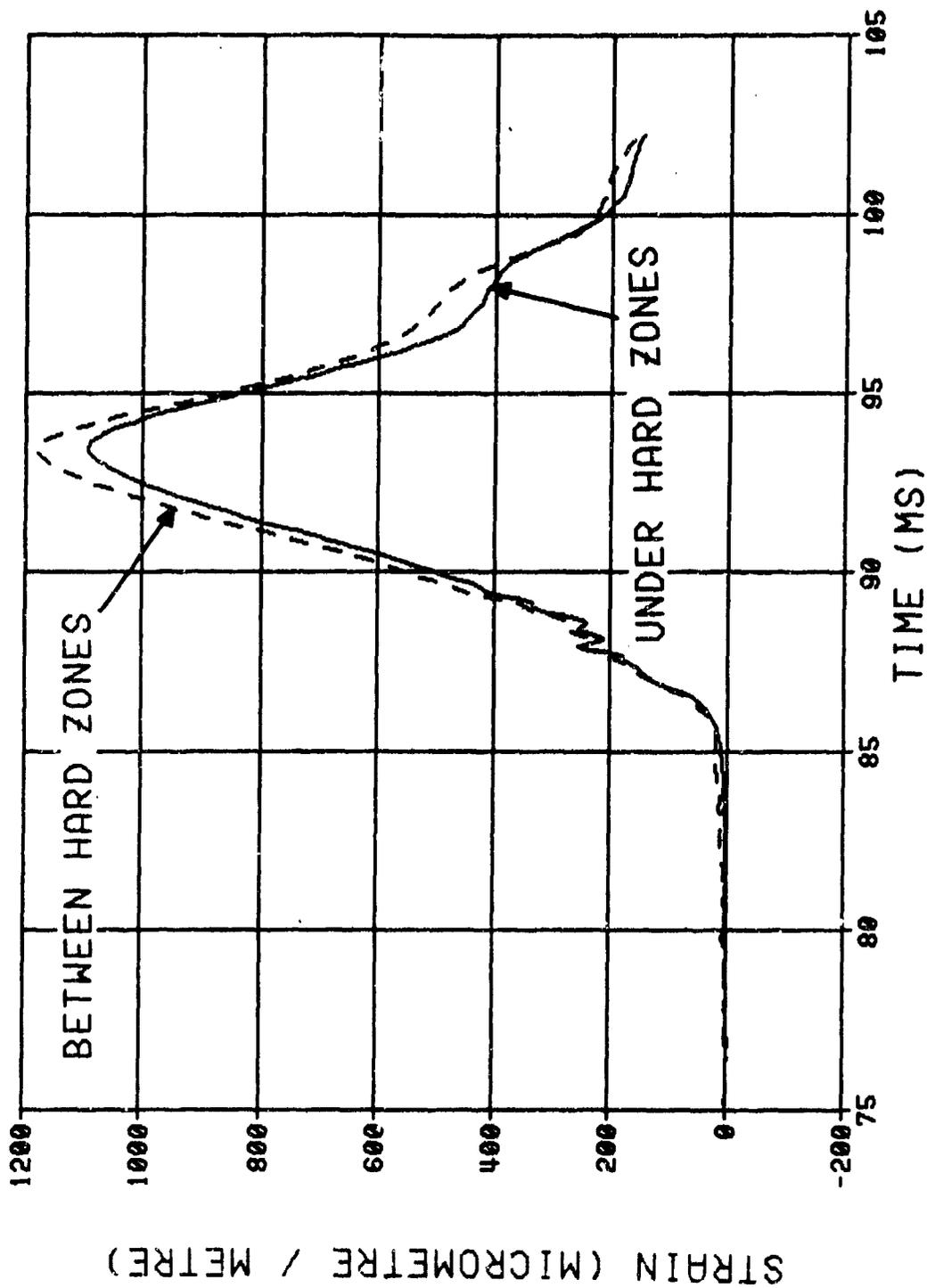


Figure 23. Strain versus Time, CLGP Warhead #3

X. CONCLUSIONS

The LCSRS and the on-board instrumentation proved to be a useful tool for this type of research project. The successful recovery of the projectiles accomplished the original task of providing warheads exposed to the launch environment for post-firing diagnostics. The data received from the projectile-mounted transducers should be useful for correlating with the theoretical analysis of the warhead structure. As this type of program becomes more routine, the real potential of these systems will be realized.

ACKNOWLEDGMENTS

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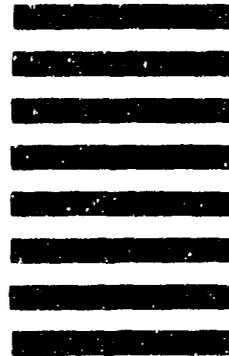
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