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PRELIMINARY MEASUREMENTS IN A SUPERSONIC GUN SIMULATOR

Second Interim Report

by

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April 1988

United States Army
European Research Office of the US Army
London, England
Contract Number DAJA 45-87-C-0045

FS / 88 / 16

ABSTRACT

The development of a high-speed gun simulator (Mark III) has been completed and it has been shown to produce transonic projectile velocities in excess of 400 m/s with initial pressures up to 60 bar. Preliminary measurements of pressure and gas velocity have been obtained using the instrumentation of the subsonic Mark II rig and were limited to initial pressures of around 1 bar with consequent gas velocities less than 50 m/s at a location close to the initial chamber. In order to extend the range of measurements to supersonic gas and projectile velocities in excess of 400 m/s new instrumentation have been developed to determine time-dependent pressure, gas velocity, and heat-flux information simultaneously and relay them to a computer within 10 μs in order to resolve the characteristics during the short cycle times of typically 7 μs.

1. INTRODUCTION

The evolution of gun simulators at Imperial College (1,2) has led to the development of the Mark III simulator which was designed to increase the projectile and associated gas velocities to the supersonic speeds close to those in real gun systems. By increasing the initial volume and travel length while reducing the mass of the projectile relative to that in the subsonic Mark II rig (1-5), the high initial pressures of up to 60 bar allow the projectile to attain velocities greater than 410 m/s at the muzzle. The objectives of the preliminary measurements in the Mark III simulator were to quantify the projectile velocity as a function of initial pressure, to determine the limitations of the instruments employed in the Mark II rig, and to provide guidance in the development of instrumentation required for the Mark III simulator. A description of the flow configuration and measurement instrumentation is presented in the following section. Preliminary results are presented and discussed in the third section and the report ends with a summary of important conclusions.

2. EXPERIMENTAL SYSTEM

2.1 Flow Configuration

The Mark III rig, Figure 1, simulates a constant-diameter preburnt propellant ideal gas gun as described by Seigel (6,7) and was designed to permit supersonic projectile and gas velocities. It is similar to those of references 1 to 5 but is designed to operate with higher initial pressures. Unlike the Mark I and II simulators, the present arrangement was oriented in a horizontal position to accommodate its considerable length.

It comprised an initial chamber of 22.2 mm (d) bore and 1.13 m (50.90d) length and a test section length of 2.43 m (109.82d) which contained seven plexiglas windows to facilitate velocity measurements with a laser Doppler velocimeter. The projectile was captured in the retarder section of the simulator which was attached to the test section via a perforated muzzle of around 20d in length. The projectile was made from Acetal plastic, weighed 13.1 g, and was initially held in place against an O-ring, to prevent leakage of the gas, by three pins resting on the cammed surface of a lock/release collar mechanism, as shown in Figure 1. Programmable solenoid valves connected to bottled zero-grade nitrogen and air were used to allow pressurizing of the initial volume with nitrogen, releasing of the projectile with the lock/release mechanism activated by a pneumatic cylinder, and the projectile's subsequent return to the locked position for a new shot.

2.2 Measurement Instrumentation

Preliminary measurements were obtained with the instrumentation employed in the Mark II rig, which is shown in Figure 2. A quartz pressure transducer (Kistler type:6121) mounted in the breech of the initial volume enabled the pressure to be monitored during the charging process and measured as a function of time during the cycle. The measurement cycle was started by the release of the projectile which uncovered, after its first 2 mm movement, a laser beam focussed on a fiber-optic relay connected to a trigger signal conditioner which in turn triggered the pressure and velocity instrumentation. A 5 mW He-Ne laser beam focussed onto a photodiode connected to a transient recorder was used to determine the projectile velocity information at each-one of the seven windows to within 0.1 m/s by recording the time-of-flight of the projectile across the beam. A laser-Doppler velocimeter powered by a 32 mW He-Ne laser was positioned at the first window station (60.81d from the breech) to measure the velocity of gas seeded by silicone oil droplets of 1 μm nominal diameter. The Doppler velocimeter arrangement enabled the fluid velocity to be resolved within 0.1 m/s and with a temporal accuracy of 0.05 ms during the cycle.

The frequency counter used in the Mark II instrumentation was limited to a maximum frequency of 10 MHz and an optical unit with a rotating grating was used to down-shift the Doppler frequencies by 5.5 MHz so that the overall frequency response of the velocimeter system was extended to around 15 MHz. With the particular arrangement of the velocimeter, this frequency range corresponded to an upper velocity limit of around 45 m/s which was adequate for the Mark II experiments. The results presented in the following section are intended to explore the capabilities of this system with the present Mark III rig and to provide guidance in the development of an improved measurement system.

3. RESULTS AND DISCUSSION

3.1 Projectile Velocity Characteristics

The projectile velocities measured with initial pressures from 10 to 60 bar (gauge) ranged from 200 m/s to 410 m/s respectively, and are shown in Figure 3, together with those calculated applying a quasi-steady isentropic expansion method, assuming negligible friction, described in references 2 and 4. The calculated time records of projectile position for the same initial pressure range are presented in Figure 4 to indicate the corresponding cycle times which varied from 8 ms to 25 ms. For initial pressures greater than 35 bar, projectile velocities at the muzzle become greater than the speed of sound (343.2 m/s). The measured projectile velocities were different from the calculated values by a maximum of 4% at pressures above 35 bar which can be attributed to friction and losses across the shock waves in front of the projectile which were not taken into account in the calculations. The overpredictions of projectile velocities relative to the measured values by less than 1% at pressures below 35 bar are caused by neglecting the effects of wall friction. Seigel (6,7) notes a similar discrepancy between measurements and calculations based on the application of isentropic theory to the interior ballistics cycle.

3.2 Pressure and Gas Velocity Results at Low Initial Pressures

Pressure time records for lower initial pressures between 1 and 8 bar (gauge) are displayed in Figure 5 together with the times at which the projectile exits the muzzle and show that at pressures greater than 2 bar, the projectile leaves the test section before the pressure at the breech decreases to atmospheric.

The measurable single-phase velocity was limited, as discussed in section 2, to around 45 m/s, thereby restricting preliminary testing to initial pressures to around 1 bar (gauge). Centerline velocity results obtained at 60.81d from the breech during 8 cycles, are shown for an initial pressure of 1 bar in Figure 6. After the projectile passes the measuring window at around 9 ms, the flow immediately behind the projectile accelerates for the next 10 ms and subsequently decelerates as the projectile moves toward the muzzle with peak-to-peak velocity fluctuations, caused by turbulence and cycle-to-cycle variations, of about 15% on average. The low pressure velocity measurements in the Mark III rig display similar flow characteristics to those of the subsonic Mark II rig in capturing the acceleration and subsequent deceleration of the flow in the wake of the projectile.

3.3 Mark III Instrumentation Development

At higher pressures, greater than 2 bar, single-phase velocity measurements were impossible because the resulting gas velocities were out of the range of the velocimeter. The development of instrumentation which can accommodate the Doppler frequencies produced by transonic velocities during very short cycle times are therefore necessary.

At an initial pressure of 60 bar, the maximum Doppler frequency associated with the 420 m/s projectile velocity is of the order of 140 MHz which is clearly outside the range of the present velocimeter. An alternative counter and method of frequency shift was required together with a computer interface characterized by fast data transfer times to accommodate small cycle times of around 7-13 ms. By employing a TSI Doppler frequency counter (Model 1990C) with an upper limit of 100 MHz and using an optical downshift of 40 MHz produced by a DISA Bragg cell, fluid velocities up to 420 m/s can be measured with an accuracy of 1% full scale (4 m/s at maximum velocity). An interface between the counter and an IBM-AT computer was therefore developed to achieve such requirements and transfer the velocity information to the computer in real-time by a direct-memory-access (DMA) in around 10 μs. The measurement of the pressure and heat transfer is accomplished with a pressure transducer and a thin-film resistance thermometer similar to those of reference 5, whose output were interfaced with the IBM-AT via an analog-to-digital board with direct-memory-access at a maximum rate of approximately 100 KHz (10 μs). The fast data transfer times are important because the total cycle times in the Mark III supersonic gun simulator are relatively small and high data rates are necessary to sufficiently resolve the pressure, velocity, and heat transfer characteristics. The development of the instrumentation system is now complete and the associated software which couples the IBM-AT computer, TSI counter, 8-channel analog-to-digital board and external triggering is near completion.

4. CONCLUSIONS

The main conclusions extracted from the preliminary tests in the Mark III supersonic gun simulator can be summarized as follows:

1. The Mark III simulator has been shown to allow projectile and gas velocities in excess of 400 m/s close to those in real guns. The measured projectile velocities were within 3% of those calculated on the basis of a one-dimensional isentropic method.

2. Preliminary measurements of pressure and gas velocity at relatively low initial pressures of up to 8 bar have been conducted and the results were qualitatively similar to those obtained in the Mark II simulator. The limitations of the Mark II laser Doppler velocimeter have impeded the measurements with initial pressure of above 2 bar and at locations downstream of the first measuring window.

3. The results confirm the need for an improved laser velocimeter able to measure velocities up to 420 m/s within 1% and communicate the results to a computer relatively quickly (100 KHz) in order to resolve the temporal characteristics lasting typically 7 ms. To this end a fast counter/computer system has been chosen and an interface between them developed to allow gas velocity measurements in excess of 400 m/s. The associated software has also been developed and is near completion.

ACKNOWLEDGEMENTS

Financial support provided by the US Army European Research Office is gratefully acknowledged. The guidance, advice, and support of Dr. Ali Bicen was of great assistance in the design and operation of the test rig. The technical assistance of John Laker and Peter Trowell is also appreciated.

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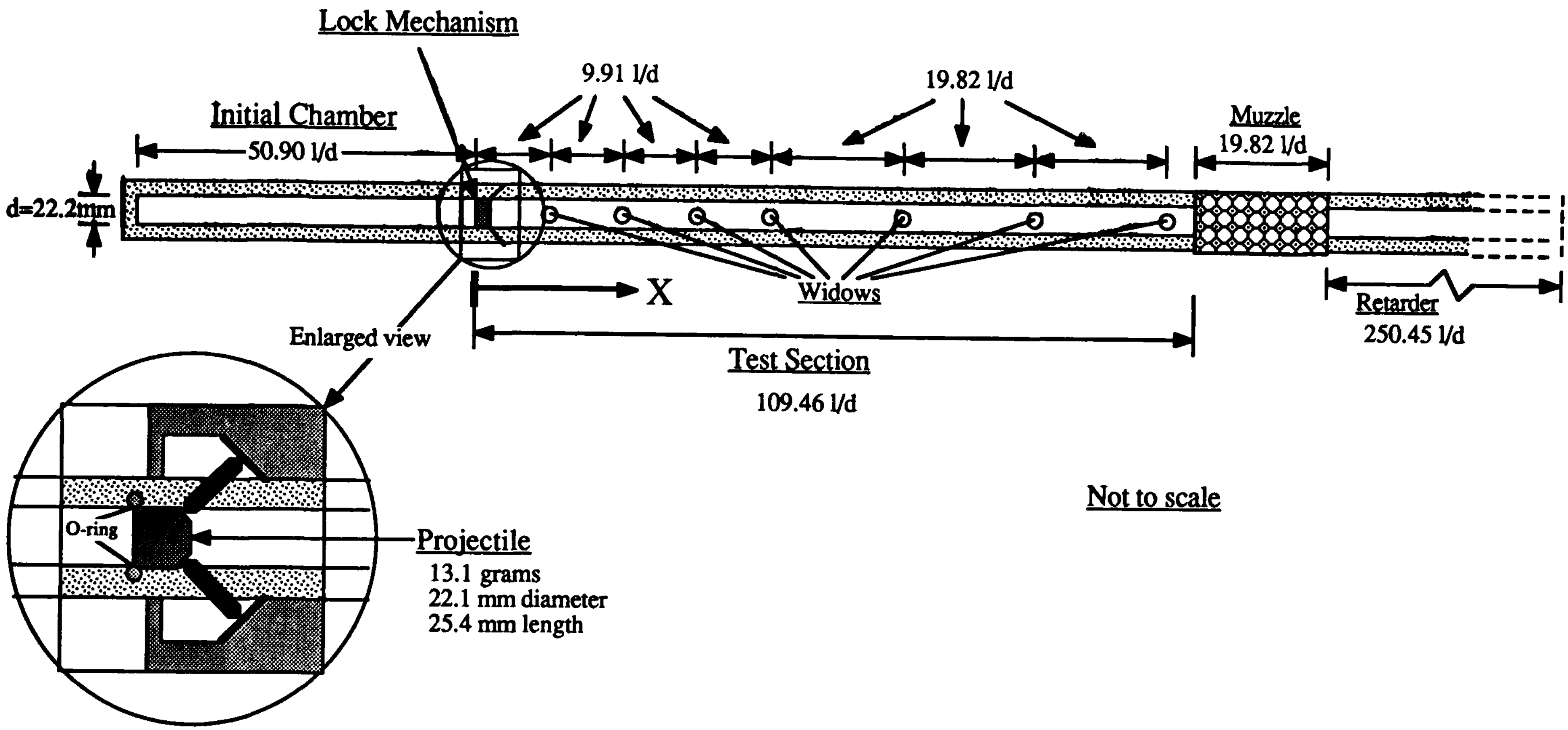

Figure 1. Geometry of Mark III supersonic gun simulator.

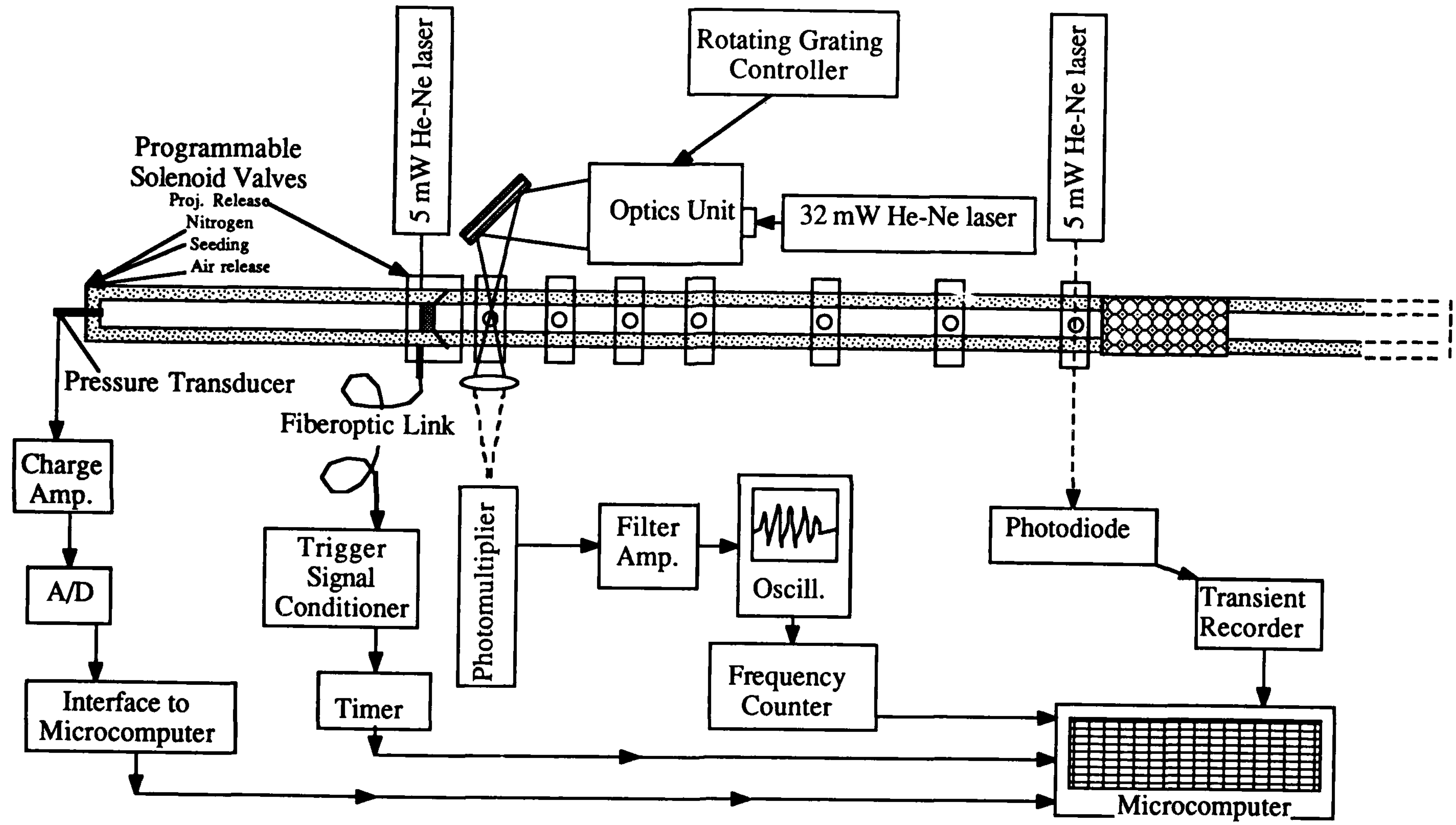

Figure 2. Schematic diagram of Mark III preliminary instrumentation.

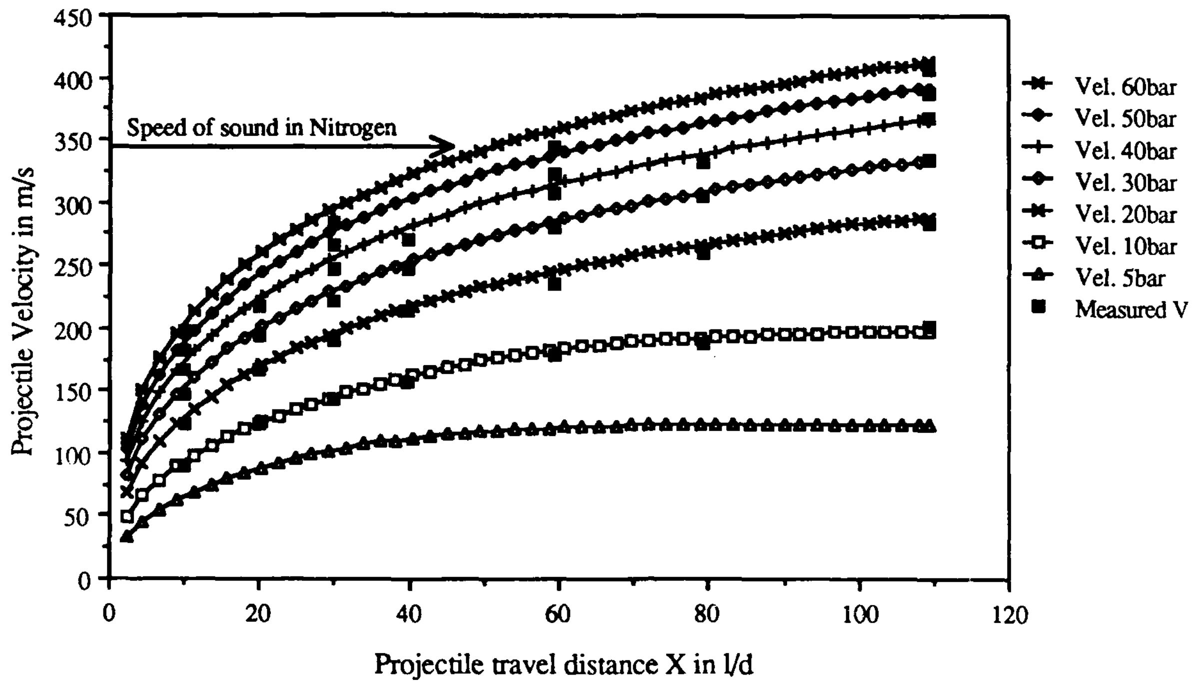

Figure 3. Measured and calculated projectile velocity versus travel distance.

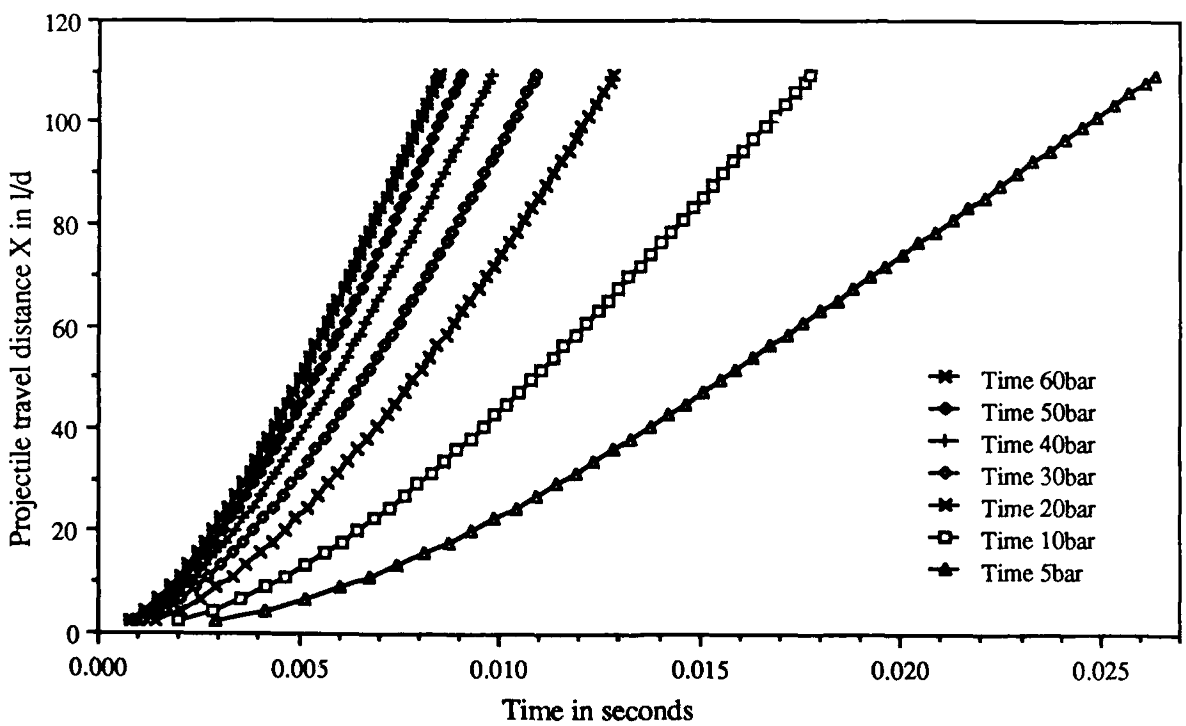

Figure 4. Calculated time of projectile position.

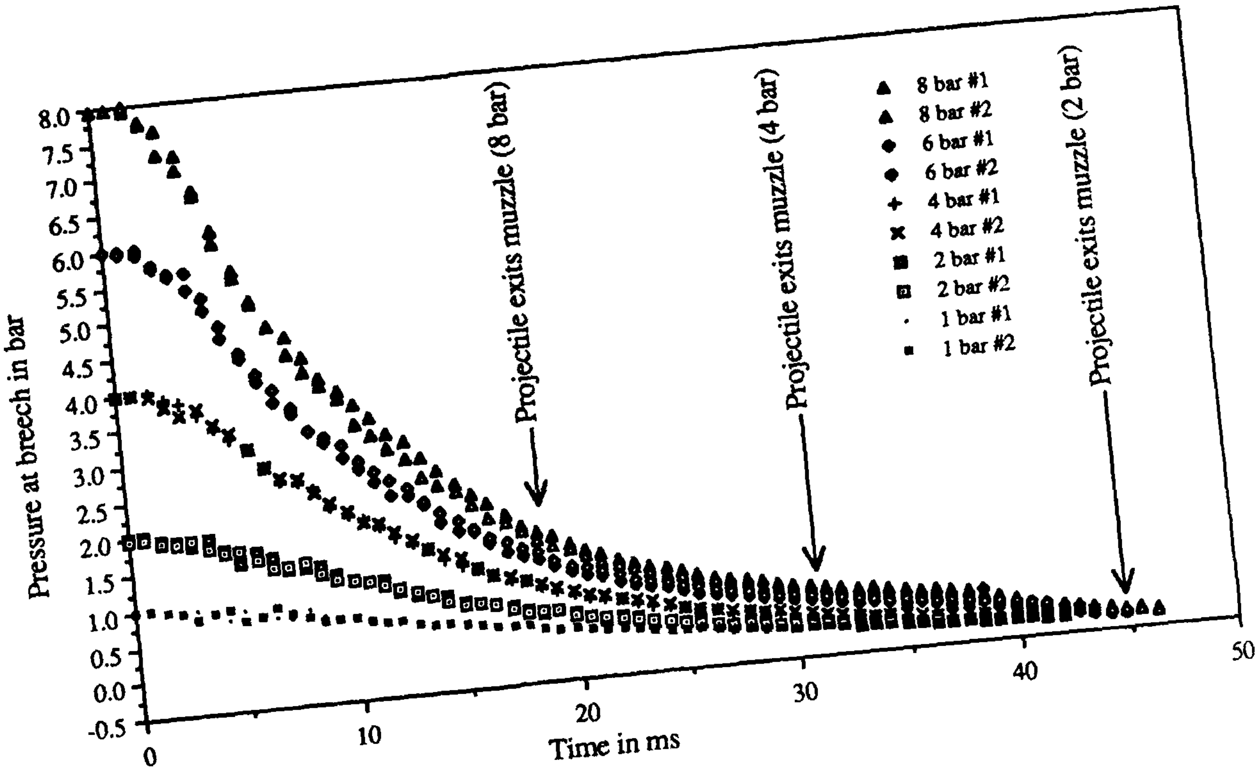

Figure 5. Pressure versus time record for 8-1 bar initial pressures.

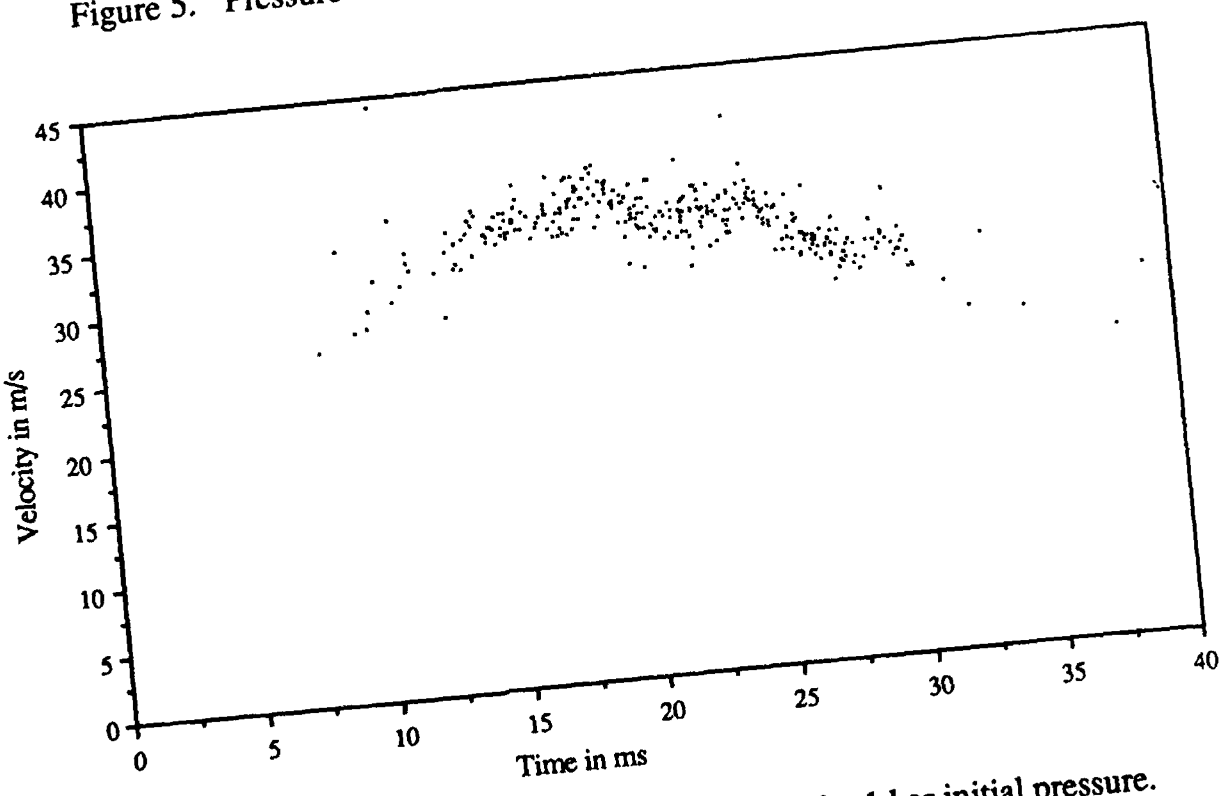

Figure 6. Centerline single-phase velocity data for 1 bar initial pressure.