FIFTH AUSTRALASIAN CONFERENCE

on

HYDRAULICS AND FLUID MECHANICS

at

University of Canterbury, Christchurch, New Zealand

1974 December 9 to December 13

GAS GUNS FOR AERODYNAMIC TESTING AT SUBSONIC SPEEDS

by

L.M. Sheppard

SUMMARY

In 1967, a gas gun of 127mm bore was constructed and it has been in almost continuous use since then. Pressures up to 3000 kPa are used. Early in 1973, a larger gas gun of 384mm bore was brought into use. This gun uses pressures up to 1000 kPa. Both gas guns have special, but different, fast acting valves for releasing gas from a reservoir into the gun barrel, behind the sabot propelling the sabot, with projectile, along the barrel. The sabot separates from the projectile after leaving the gun barrel. A typical peak acceleration is 5000 m/s^2. The performance of both guns is discussed and comparisons given with predictions made using a simple adiabatic expansion theory and a modified theory using quasi-steady corrections for the pressures acting on the sabot. The motion of the novel fast acting sleeve valve on the 384mm gun is compared with predictions from a computer simulation of its motion. The results highlight the value of developing a computer programme to simulate the coupling of the sleeve valve motion to the gas flow out of the high pressure reservoir and to the movement of the sabot up the gun barrel.

L.M. Sheppard, Principal Research Scientist, Weapons Research Establishment, South Australia

1. INTRODUCTION

In 1967 during an investigation into the flight of lifting projectile shapes, it was suggested that a gas gun could be used to fire single projectiles, by using sabots, and that measurements could be made of their subsequent flight. A gun of 127mm bore was constructed and has been in almost continuous use since its first firing late in 1967 (1). Pressures up to 3000 kPa are used. Sabot speed is measured at the muzzle of the gun. The gun has been used for tasks ranging from the statistical study of projectile impact patterns to assisting in the development of a W.R.E. image synchronization camera. Early in 1973, a larger gas gun of 384mm bore was brought into use to study the flight of large projectiles and clusters of small projectiles. This gun uses pressures up to 1000 kPa. The two gas guns, together with associated instrumentation, constitute the W.R.E. Gas Gun Facility. Airborne and ground instrumentation systems, including telemetry are used. Parachute recovery systems are available.

The whole Facility has been described by Evans (1). It is used to assist in both aerodynamic research and the development of small munitions in a close-to-the-laboratory environment where remote and extensive Range facilities such as those at Woomera in South Australia are not necessary.

The gas guns, a control and recording building and pressurizing equipment are located at one end of an area approximately 1100 metres by 600 metres in size. The ground instrumentation includes some fixed wide-angle ballistic cameras which are used at night to determine projectile position and velocity throughout flight. A light flashing at a frequency of about 15 Hz is carried in the projectile and the light flashes are recorded on the ballistic camera plates. High speed cameras are used during some day firings to record the performance of the sabot and the subsequent flight of the projectile.

2. GAS GUNS

A photograph of the two gas guns is shown in figure 1. The smaller 127mm gun has a barrel 4.5 m long and a high pressure storage chamber with a volume of 0.032 m^3. The sabots are muzzle loaded and the gun is fired by a quick acting valve. The valve is held shut by ensuring that the force on one side of a piston is greater than on the other side. It is opened by suddenly venting to atmosphere the high pressure on one side of the piston, causing the piston to move rapidly (2).

The 384mm gun has a barrel 6 m long and a gas storage volume of 0.68 m^3. Sabots may be large and heavy, and are breech loaded as shown in figure 2. The gun is fired by a special quick acting sleeve valve which is opened by suddenly reducing the pressure on one side of a piston. Initially, the piston is pressed against a seal on the reservoir (figure 3). The force on the rear of the piston is quickly reduced by opening up to eight quick acting firing valves and when it falls below the force on the front face the piston starts to move backwards. When it does, vents in the barrel begin to be uncovered and air flows from the storage reservoir into the barrel behind the sabot. The sabot is forced up the barrel and ejected from the muzzle in a time of 50 ms or so. The piston moves rapidly rearwards and is decelerated by compressing air behind the piston, as well as by a rubber buffer.

When the 384mm gun was first designed it was not known whether the piston would remain on and near the rubber buffer or bounce forwards. To answer this question and to predict the performance of the gun, a computer program (3) was developed to model the system behaviour.

3. PERFORMANCE OF GUNS

A simple, useful method of predicting gun performance has been described by Perfect (4). The gas is regarded as being at rest, and the quick acting valves are assumed to open fully immediately the gun is fired. The pressure behind the sabot and throughout the reservoir is calculated by assuming an adiabatic expansion from the storage volume to the new enlarged volume. Atmospheric pressure is assumed to act on the front face of the sabot. By writing the sabot acceleration $\frac{dV}{dt}$ as $\frac{VdV}{ds}$, where V is velocity and s distance travelled along the barrel, the equation of motion can be integrated analytically to give a simple expression for the muzzle velocity.

Measurements of muzzle velocity showed fair agreement with the simple theory. An attempt was therefore made to devise an improved theory, keeping the procedures as simple as possible. The unsteady gas motions behind and in front of the sabots are accounted for by using quasi-steady pressure formulae. Again the quick acting valve is assumed to open fully immediately the gun is fired. A computer program was written to do the necessary numerical calculations.

The pressure on the front face of the sabot is assumed to be the same as the stagnation pressure on a sabot moving at a constant speed equal to the instantaneous speed of the sabot. Similarly, the pressure on the rearface of the sabot is assumed to be equal to the static pressure under conditions where the steady speed is the same as the instantaneous speed and the steady stagnation pressure is equal to the instantaneous pressure calculated from the simple theory. Standard isentropic flow formulae are used.

Some results for the muzzle velocity of the 127mm gas gun are given in table 1 below. The measured velocities are taken from calibration curves derived from numbers of gun firings (2).

TABLE 1

PERFORMANCE OF 127mm GAS GUN

MASS (INCL. SABOT) kg	STORAGE PRESSURE kPa	MUZZLE VELOCITY (m/s)		
		SIMPLE THEORY	MODIFIED THEORY	MEASURED
2.3	690	118	112	105
	1380	175	162	155
	2070	218	196	189
	2760	253	222	-
4.5	690	84	81	72
	1380	124	119	109
	2070	154	146	136
	2760	179	167	158
9.1	690	59	58	49
	1380	87	85	77
	2070	109	106	97
	2760	126	122	113

Comparing the two predictions in the table with each other and with the measured velocities shows that the actual muzzle velocity is less than either prediction. However, the improved quasi-steady predictions are nearer the actual measurements, particularly at the higher muzzle velocities.

Corresponding results for the 384mm gas gun are shown in table 2.

TABLE 2

PERFORMANCE OF 384mm GAS GUN

MASS (INCL. SABOT) kg	STORAGE PRESSURE kPa	MUZZLE VELOCITY (m/s)		
		SIMPLE THEORY	MODIFIED THEORY	MEASURED
14.5	345	119	111	103
	690	181	165	152
	1030	226	200	184
29.0	345	84	81	75
	690	128	122	112
	1030	160	150	138
58.1	345	59	58	53
	690	90	88	82
	1030	113	110	101

In this case also, improved predictions are given by the quasi-steady theory at the higher muzzle velocities. When account is taken of the actual gas flows and the time taken for the quick acting sleeve valve to open, by using the special gun computer program (3), results with eight firing valves operating differ from the results of the modified theory by, at most, 2 m/s in muzzle velocity. Larger differences occur when less than eight valves are used and the sleeve valve opens less rapidly.

4. PISTON MOTION

The gun computer program (3) has been developed to predict both the performance and the piston motion of the 384mm gas gun. Three general types of piston motion have been predicted. For the first type, the piston moves back near to or on the rubber buffer and stays near the buffer. Examples are shown in table 3, together with measurements of piston position. No other measurements are available. Time has been measured from the time when the piston reached the first position measuring point. In all cases eight firing valves are used and there was no sabot. The piston motion is predicted to be less violent when sabots are used.

TABLE 3

PISTON MOTION IN 384mm GAS GUN WITH NO SABOT AND EIGHT VALVES IN USE

RESERVOIR PRESSURE kPa	TIME ms	PISTON POSITION (mm)	
		PREDICTED	MEASURED
140	0	0	0
	10	62	28
	20	137	79
	30	195	112
	40	166	137
	Piston at rest	-	124
210	0	0	0
	10	73	52
	20	156	100
	30	183	146
	40	161	184
	Piston at rest	-	194
280	0	0	0
	10	78	77
	20	164	141
	30	182	191
	40	170	200*
	Piston at rest	-	196

* The rubber buffer is located at the 198mm position

The agreement between the predictions and the measurements is not very good at the lowest pressure. However, agreement is much improved at the highest pressure. It is believed that much better agreement would be achieved if the effects of friction on the piston motion were included in the computer model. This has not been done. Further measurements of piston motion will be made, extending the pressure range into the region of normal gun operation and up to 1000 kPa.

The second type of piston motion shows large piston oscillations between the buffer and the reservoir seal, and no contacts with either the buffer or the seal. The third type of piston motion is similar to the second type, but the piston now hits the reservoir seal. In general, this occurs when the sabot is very light, or there is no sabot, and no more than six quick release valves are used.

In order to avoid expensive piston damage the gun is not operated near conditions leading to the third type of piston motion. All eight quick release valves are used to fire the gun even though with some combinations of sabot mass and reservoir pressure a smaller number of valves could safely be used.

5. CONCLUSION

The 384mm gas gun computer program enables good simulation of the gun operation to be made. In particular, good performance predictions are made and potentially damaging operating conditions have been identified. This highlights the value of using computer simulations in development activities.

ACKNOWLEDGEMENT

Many people have contributed to the W.R.E. Gas Gun Facility. The author has had helpful discussions with N.J. McKellar on the performance of the 384mm gun, on calibration data and on piston motion. The computer program describing the operation of the 384mm gun was developed by J.R.V. Groves, W.B. James and J.B. Moran.

REFERENCES

1. Evans, H.W. "A description of the gas gun facility, Aerospace Division, W.R.E." WRE-TM-645 (WR&D) May 1972

2. Dudley, R.E. "The development of a gas gun to study the subsonic flight of projectiles" WRE-TN-639 (WR&D) April 1972

3. Groves, J.R.V. "A computer model of a large gas gun" WRE-TM-510 (WR&D) November 1971

4. Perfect, D.A. "The development of a smooth bore gun for the projection of bird carcases" R.A.E. TR 66008 January 1966

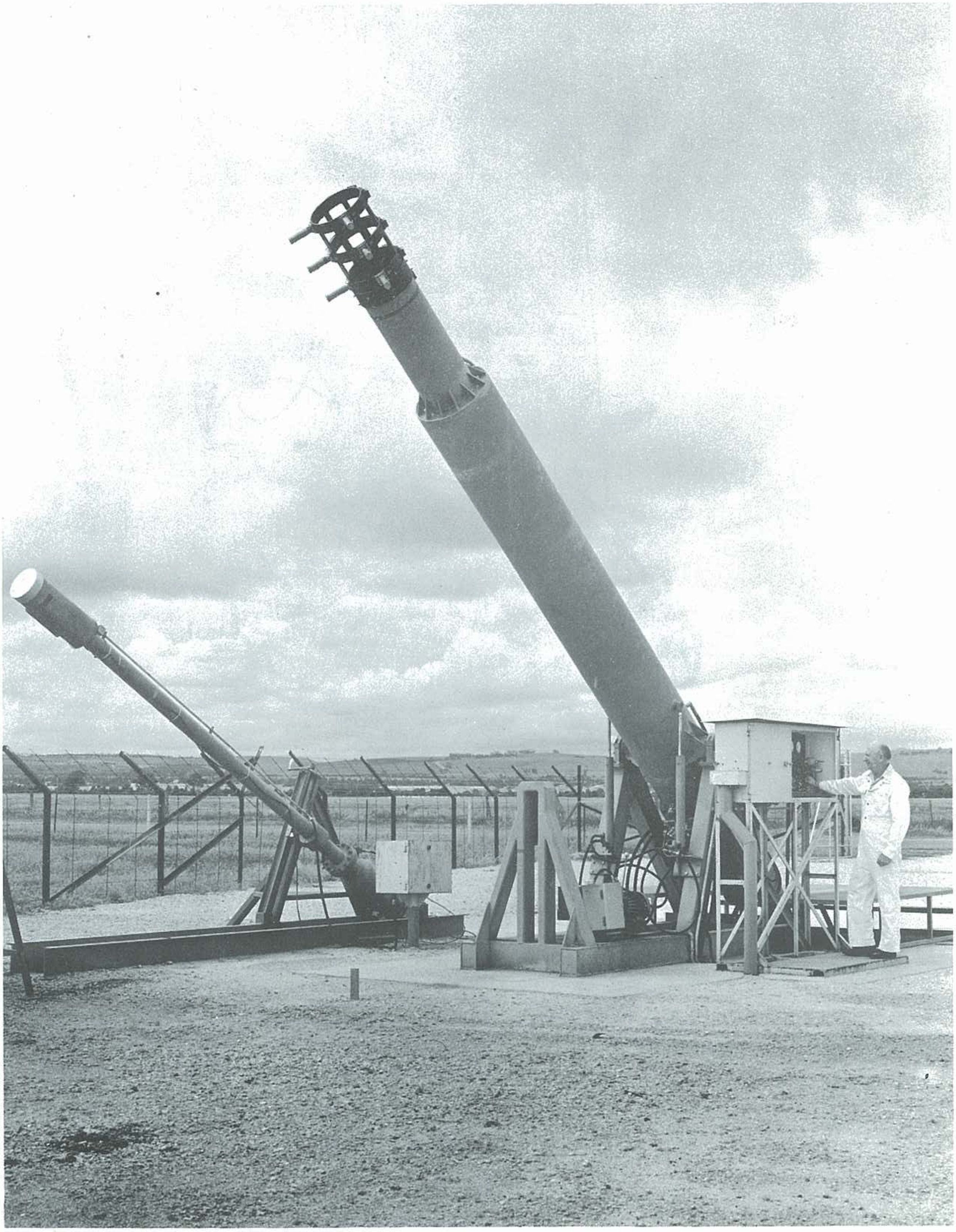

FIG.1 W.R.E. GAS GUNS

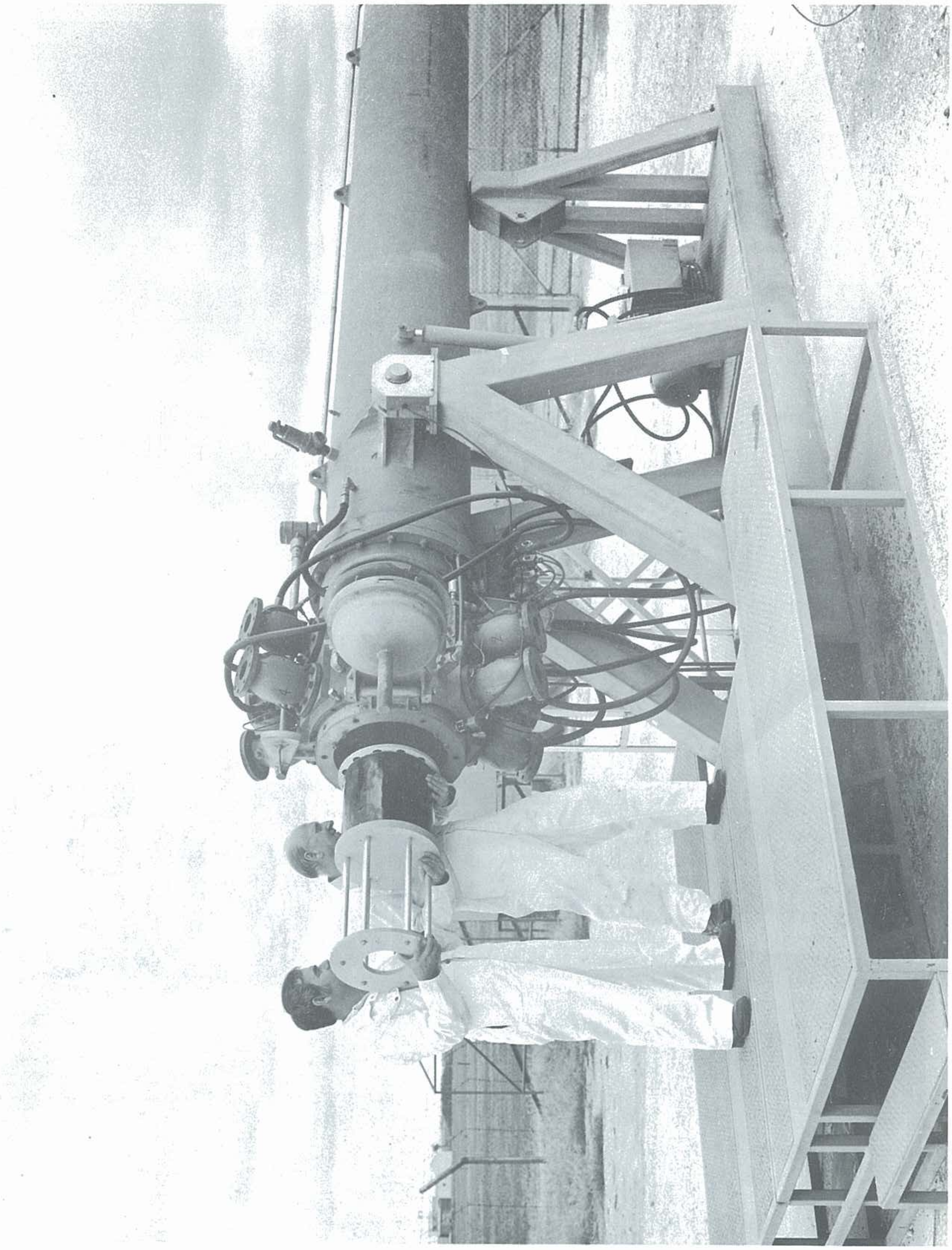

FIG.2 SABOT AND 384mm GUN

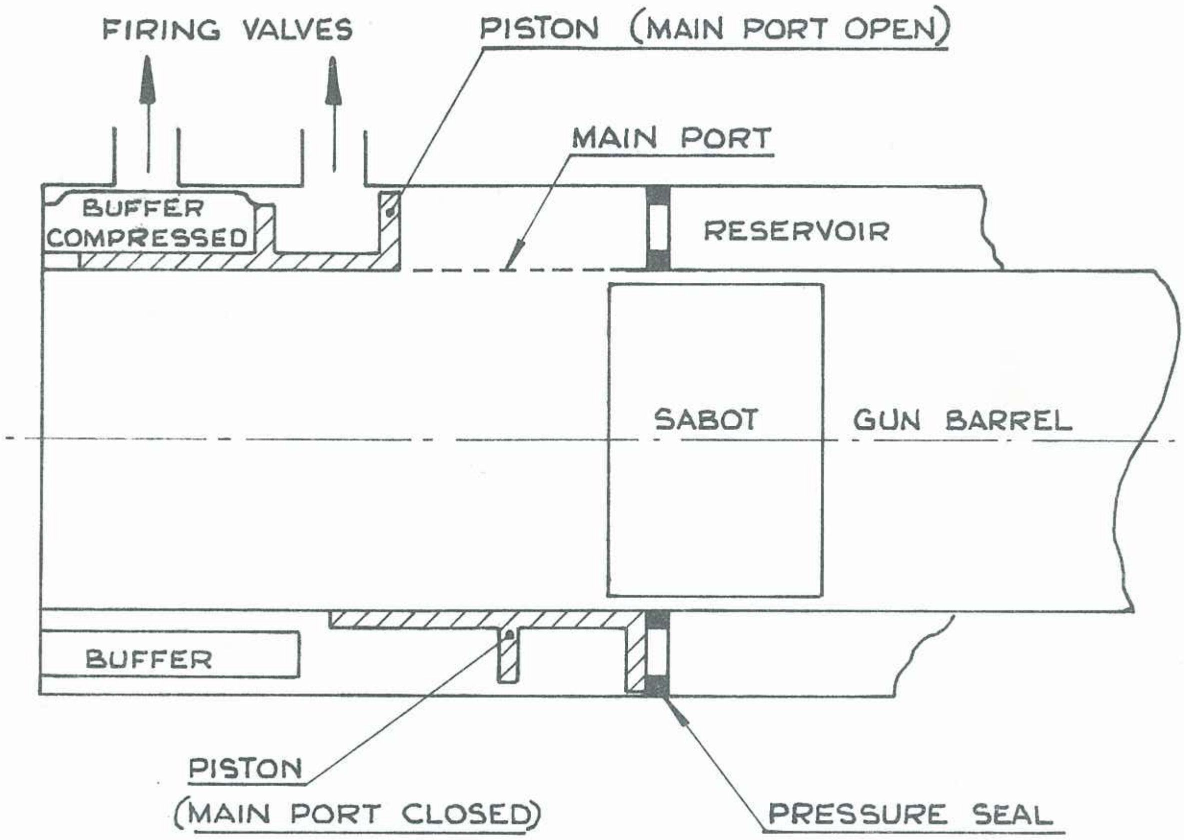

FIG. 3.

SLEEVE VALVE OF 384mm. GUN.