THE UNIVERSITY OF MICHIGAN
College of Engineering
Department of Mechanical Engineering
Cavitation and Multiphase Flow Laboratory

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# A REPEATING WATER GUN DEVICE FOR STUDYING EROSION BY WATER JET IMPACTS

by

Edward E. Timm
Frederick G. Hammitt

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## ABSTRACT

A description is given of an apparatus for discharging jets of water for experiments in simulated rain erosion of aircraft materials. The apparatus has been found to be capable of projecting jets at jet tip velocities up to 550 meters/sec and of repetitively projecting jets with tip velocities of 522 meters/sec and a standard deviation of 1.8 % from this figure. The method used for analyzing the jets is explained.

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# I. INTRODUCTION

The apparatus described in this report was constructed for experiments on the effect of water jets impacting on solid surfaces. The principal object of these experiments is to study the erosion of materials of the type used in high-speed aircraft or missiles. This is to be done particularly to evaluate the resistance of aircraft materials such as radome surfaces, etc. to rain erosion.

At present time there are three accepted rain erosion test methods. These are:

1. Use of actual aircraft in rainstorm
2. Test specimens exposed on rocket sled driven through a simulated rainfield,
3. Test specimens attached to a whirling arm rotated in a simulated rainfield.

All of these methods have the drawbacks in varying degree of high expense per test and imprecise control of conditions. It is therefore desirable to develop an alternate more economical test method for evaluating rain erosion resistance.

Two main approaches are being followed in this laboratory in trying to develop an alternative test. These are:

1. Cavitation resistance testing. It is assumed that since the damage mechanism of cavitation is presumably the impact of microjets and shock waves formed by the collapse of bubbles in the liquid, materials should have similar cavitation and rain erosion resistance;
2. Jet impact testing. This must assume that the impact of a spherical drop and a cylindrical jet cause damage by similar mechanisms and hence are comparable.

The first of these approaches has been pursued in this laboratory for about two years and more recently an investigation has been made into the second for comparison pruposes. Thus it became necessary to develop an apparatus to project high velocity water jets in an automated repetitive fashion at target specimens. Jet diameter should be of the order of 1 mm and velocity between 1000 and 2000 ft/sec to meet present needs.

H. F. Kenyon [(1)] of Associated Electrical Industries Ltd. has developed an apparatus suitable for such work, in his case for study of erosion of steam trubine blades under wet steam droplet impact. His design has been used as a guide in the design and development of the apparatus described herein. The apparatus constructed in this laboratory is thus similar to Kenyon's in principle but differs in detail.

## II. THE APPARATUS

### A. General Principles

Figure 1 is a schematic drawing of the apparatus. It shows that this device, hereafter referred to as a jet gun, projects high speed jets by a momentum exchange principle. A conical chamber formed in a steel plate, is sealed on the back with a relatively thick steel diaphragm. The chamber is filled with water or the fluid to be studied and the diaphragm is then struck by a steel bolt propelled by a heavy spring. Upon striking the diaphragm the bolt transfers a portion of its momentum to the diaphragm some of which is then imparted to the water in the chamber. This causes the water to issue from the orifice in the form of a jet at a high velocity. The resultant jet is very similar in velocity and appearance to that achieved with a gas gun momentum exchange device as developed by Bowden and Brunton[2] and also used in this laboratory [3] and elsewhere. It provides the automated features of a direct acting device as a diesel injector (which requires a close-fitting tolerance seal and which was tried unsuccessfully in this laboratory) with the sealed-fluid features of the gas gun momentum exchange device, thus in a sense combining the best features of each.

It has been found both from previous work here and from Kenyon's work that the following factors affect the jet gun performance:

1. Chamber geometry
2. Bolt size, mass, shape, and probably material
3. Bolt velocity
4. Position of meniscus in orifice at time of firing
5. Diaphragm material and thickness.

It is therefore necessary to regularize and optimize each of these variables for repeatable and desirable gun performance.

## B. Description of Gun and Gun Assembly

This apparatus consists of two parts. These are the gun itself, a closeup of which is shown in Fig. 2, and the entire gun assembly consisting of the gun alone with the mechanism and controls required to repetitively fire it, as shown in Fig. 3.

A valuable check of gun performance could be obtained from Kenyon's data if our gun was designed to be similar to his with respect to chamber design. Hence the chamber for this gun has been built to the same dimensions used by Kenyon. Thus an approximate 1/16" orifice diameter was used. Exact duplication of Kenyon's gun includes only the orifice and chamber design. The device is driven by a variable speed motor drive for any desired spring compression through a range of 5 - 110 shots per minute. A cam operated bank of microswitches automatically prepares the gun for each shot by actuating appropriate solenoid and solenoid valves, and a remote control panel capable of overriding the automatic controls on the gun assembly has been provided for manual or single shot operation.

For a given chamber geometry, bolt size, and diaphragm material gun performance is a function of the two remaining variables: bolt velocity, as controlled by spring compression, and meniscus position. Since it is desired to project jets of a known, uniform, and repeatable nature, it is necessary to have these variables fixed for each shot in a series.

Bolt velocity may be fixed by compressing the spring a known distance for each shot.

Meniscus position can be fixed by a proper setting of the controls.

## III. ANALYSIS OF JETS

### A. General Methods

Once the portion of the gun shown in Fig. 3 was constructed, it was decided to analyze its performance before proceeding with development of the motor drive assembly. This was done by photographing the jets projected from the gun with a Beckman and Whitley Model 330 camera. This camera is a continuous access streak and framing camera which takes a sequence of 80 frames at rates up to $2 \times 10^6$ frames per second. The jets were illuminated with a xenon arc which could be activated for a given duration thus preventing double exposure while the capping shutter of the camera was open. This light source was focused on the jets by means of a condensing lens.

The film from the camera was processed in the normal manner and individual prints were made from this film. By knowing the frame number of each print and the framing rate of the camera, a time-shape history for each jet photographed became known. Fig. 4 shows three typical jets projected under different operating conditions.

By examining the position of the tip of the jet in relation to a metric scale fixed on the gun for several frames, a time-distance curve could be plotted for each jet. It was found that except for lower jet velocities which exist close to the orifice plate, this curve was actually a straight line and hence jet velocity could be taken as the slope of the line.

In this manner, information became known about jet tip velocity and shape for about 50 jets projected under various operating conditions.

B. Results of Photographic Analysis

It was desired to optimize gun performance with respect to jet tip velocity and jet uniformity. The effect of a change in bolt head size, bolt weight, spring compression, and meniscus withdrawal was studied by holding all but one of these parameters constant and studying the effect of varying this single parameter on jet tip velocity and jet shape. Each of these are discussed separately:

1. Bolt Head Size

Runs were made with constant bolt weight, spring compression, and meniscus withdrawal to determine the effect of bolt head diameter.

Head diameters of 0.5, 0.7, 0.75, 0.9, and 0.95 inches were used. It was found that jet tip velocity was maximum with an 0.7 inch diameter bolt head.

2. Bolt Weight

Runs were made with constant bolt head diameter, spring compression, and meniscus withdrawal to determine the effect of bolt weight. Two bolts were used; one weighing 0.73 lb., and one weighing 0.36 lb. It was found that the lighter bolt caused a substantial loss of jet tip velocity.

3. Spring Compression

Runs were made at constant bolt weight, bolt head diameter, and meniscus withdrawal to determine the effect of spring compression (Fig. 5). It was found that velocity was linear with spring compression over most of the range.

4. Meniscus Withdrawal and Jet Shape

Runs were made at constant bolt weight, bolt head size, and spring compression to determine the effect of meniscus withdrawal to different positions in the orifice (Fig. 1). Meniscus withdrawal was measured by the volume of water withdrawn from the chamber after the meniscus was made coincident with the surface of the orifice plate. Fig. 6 shows the result of these runs. The increase of jet tip velocity found when the meniscus is withdrawn is thought to be caused by the formation of a small "Monroe jet" by a similar mechanism to that found in shaped explosive charges. Such small leading jets are typical also of the gas gun momentum exchange device.

Fig. 4 shows the three basic jet shapes. (The vertical black line in the center of the pictures is the portion of the image used to make a streak photograph of the event.) These seem to be a function of meniscus position only. Type 1 with its characteristic mushroom shape corresponds to a convex or very slightly withdrawn meniscus. Type 2 with its irregular mushroom shape corresponds to a withdrawal of 0 to about 0.025-0.03 cc of water, and Type 3 corresponds to the withdrawal of 0.04 to 0.06 cc of water. If more water than this is withdrawn the jet degenerates into a spray with little damaging potential. Fig. 6 shows the relation of water withdrawal to jet tip velocity at constant spring compression. It is noted that the regions of observed jet shape correspond roughly to regions of observed jet tip velocity. That is: Type 2 jets approach a maximum constant velocity around 0.015 cc withdrawal until with further withdrawal Type 3 jets are observed to form, whereupon the velocity increases to a maximum and falls as jet shape degenerates with still further withdrawal.

It seems likely that a jet tip velocity slightly less than the maximum obtainable was likely to be the highest jet tip velocity consistent with a well defined jet shape, and hence the most damaging.

Since this device is to be used to test materials by repetitive firing, it is necessary that jets remain highly similar throughout a run. Photographic studies were made of six Type 3 jets fired with the same operating parameters. Analysis of these photographs showed six similarly shaped jets with a mean tip velocity of 522 meters per second and a standard deviation from this mean of only 1.8%. While photographic analysis is necessary to calibrate other devices in order to see what is actually being measured, a photocell arrangement is used for ordinary monitoring of jet velocity.

## V. CONCLUSIONS

A bench-scale economical device has been developed for testing of materials for droplet impact resistance in the 1000-2000 ft/sec range with liquid slug diameters of the order of 1-2 mm. This is an automated, repeating device capable of impacting the order of 30 liquid slugs per minute on a selected target material.

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3) F. G. Hammitt, et al, "Laboratory Scale Devices for Rain Erosion Simulation," Proc. 2nd Meersburg Conference on Rain Erosion and Allied Phenomena, pp. 87-121, 16-18 Aug., 1967, edit. A. A. Fyall and R. B. King, RAE, Farnborough, England.

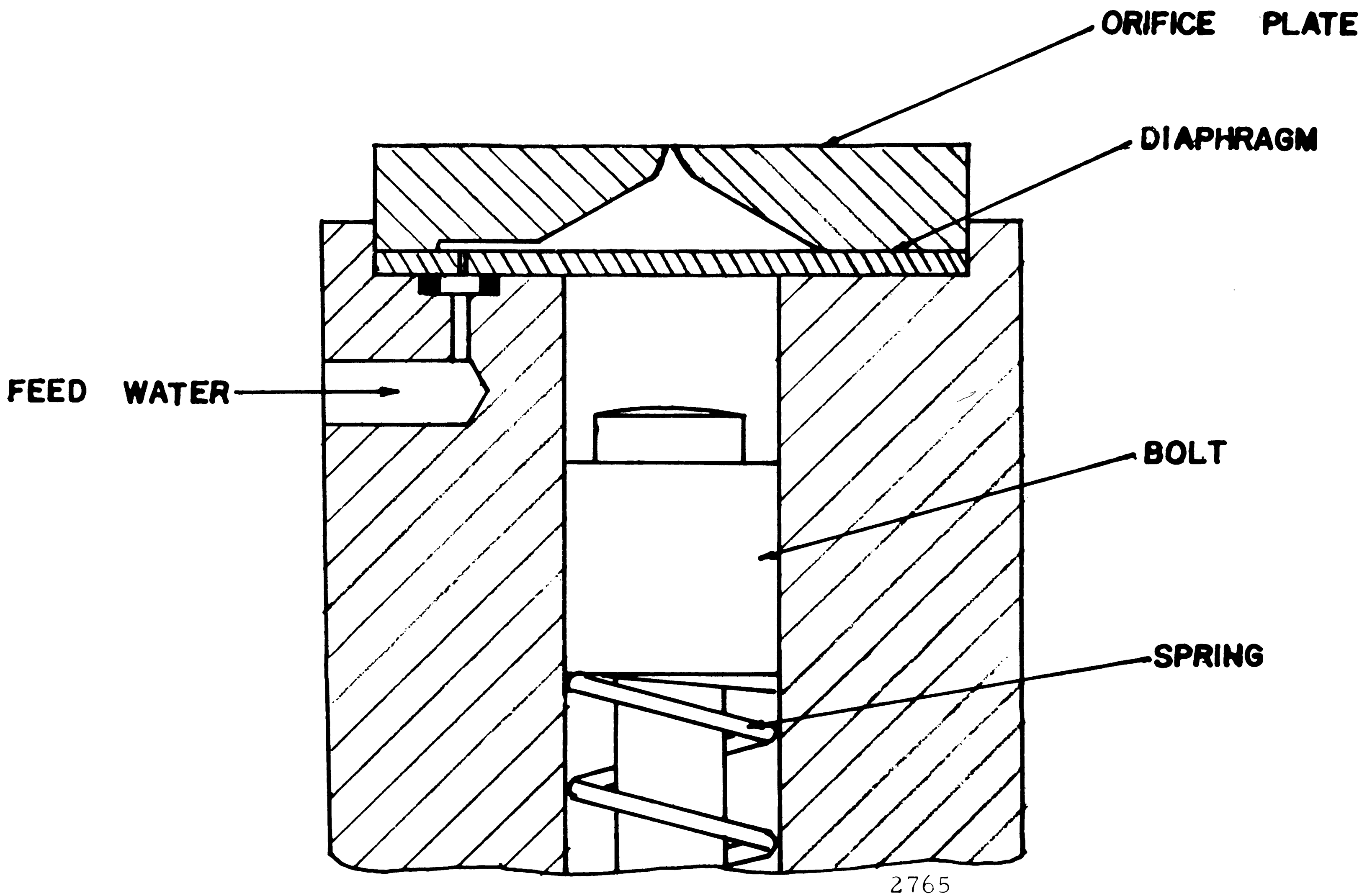


Fig. 1. Schematic of Repeating Water Gun Device

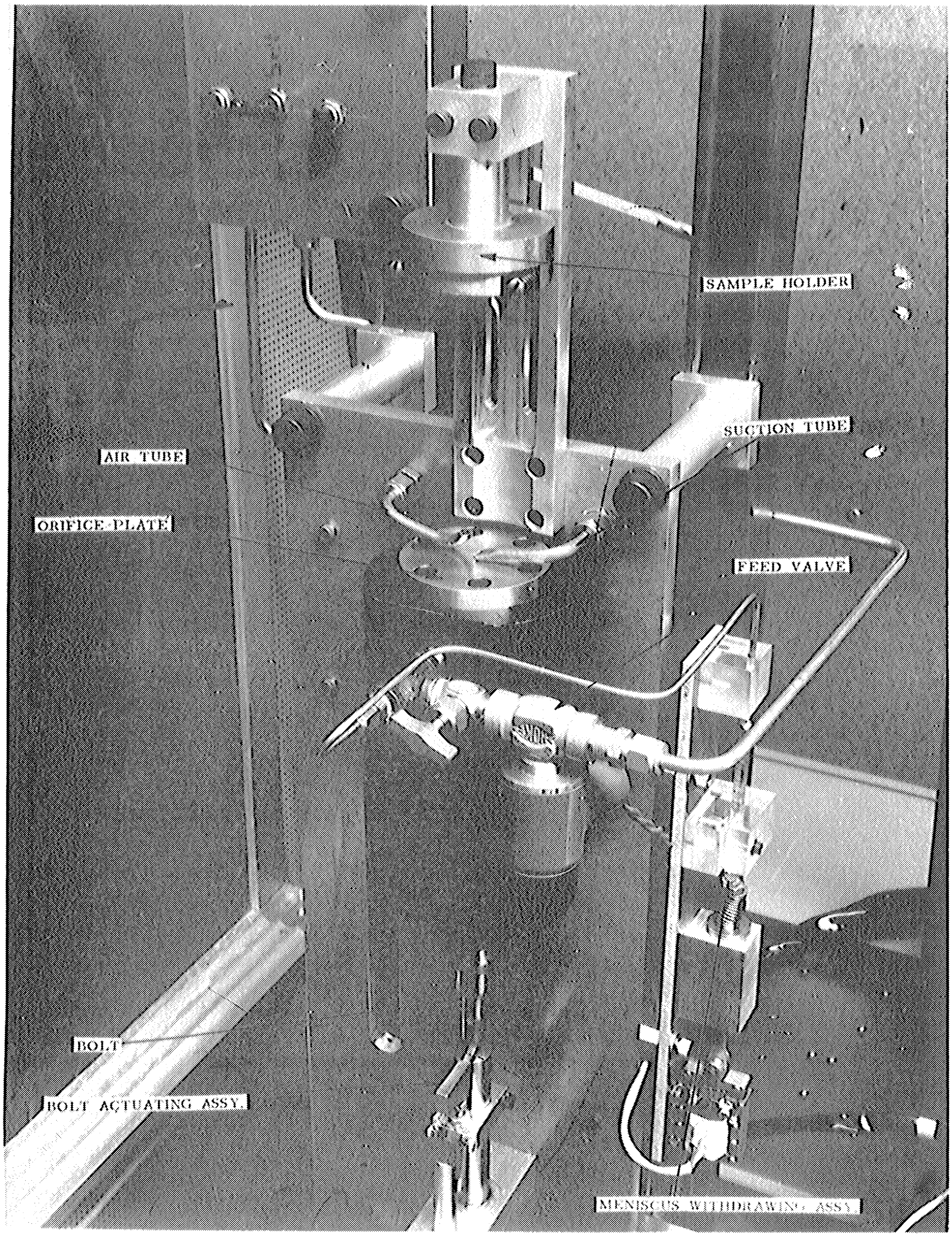


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Fig. 2. Repeating Water Gun Device

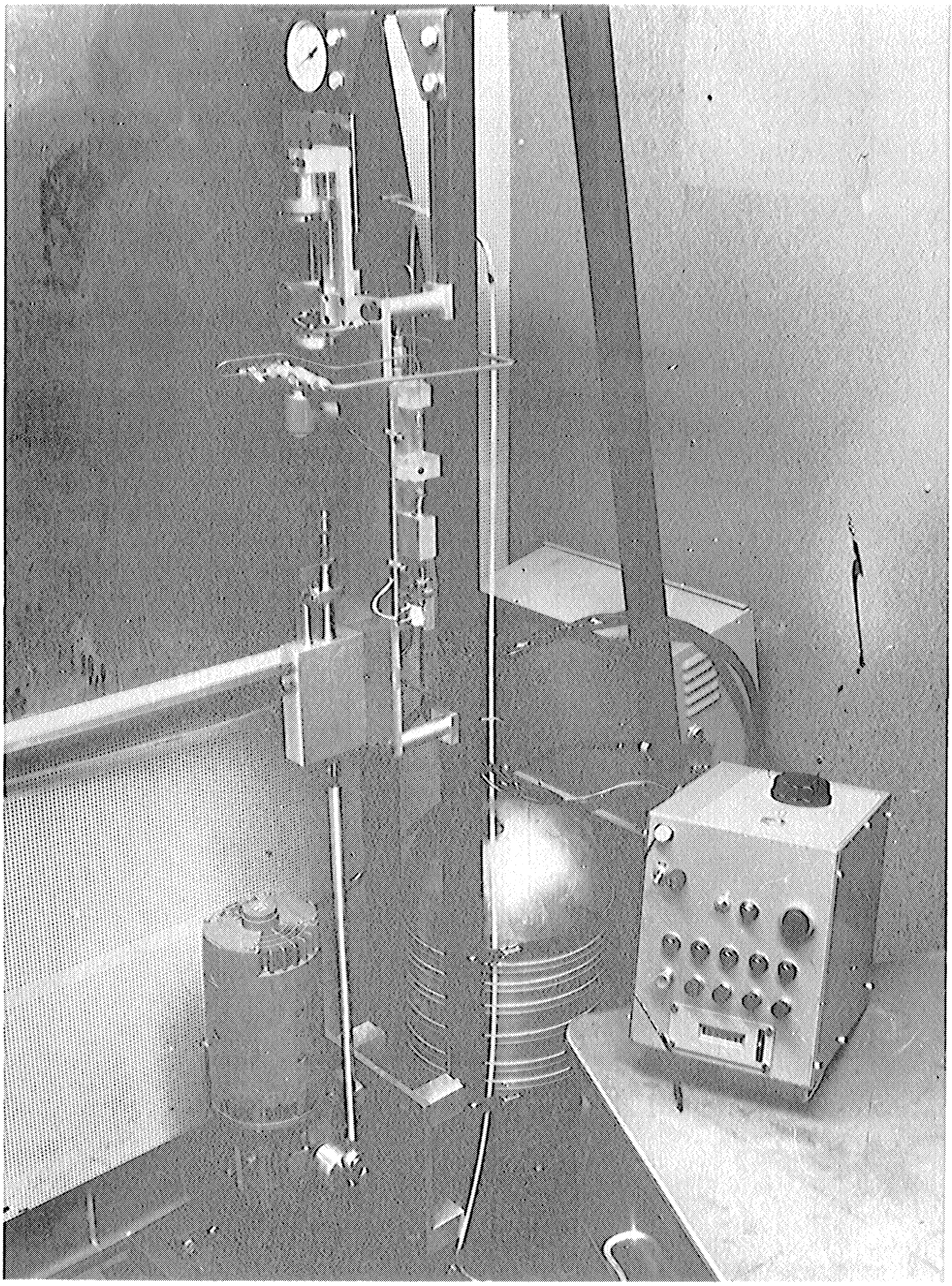
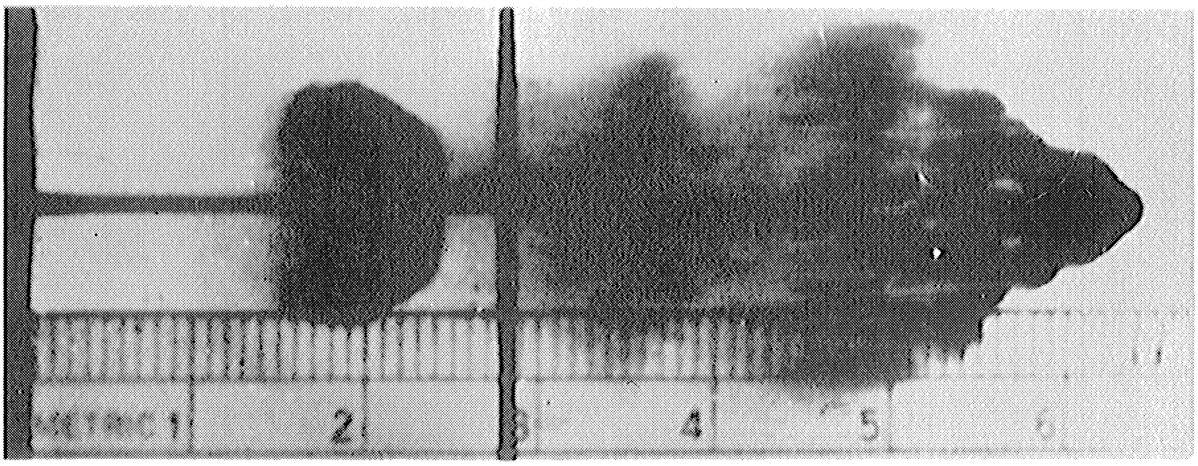
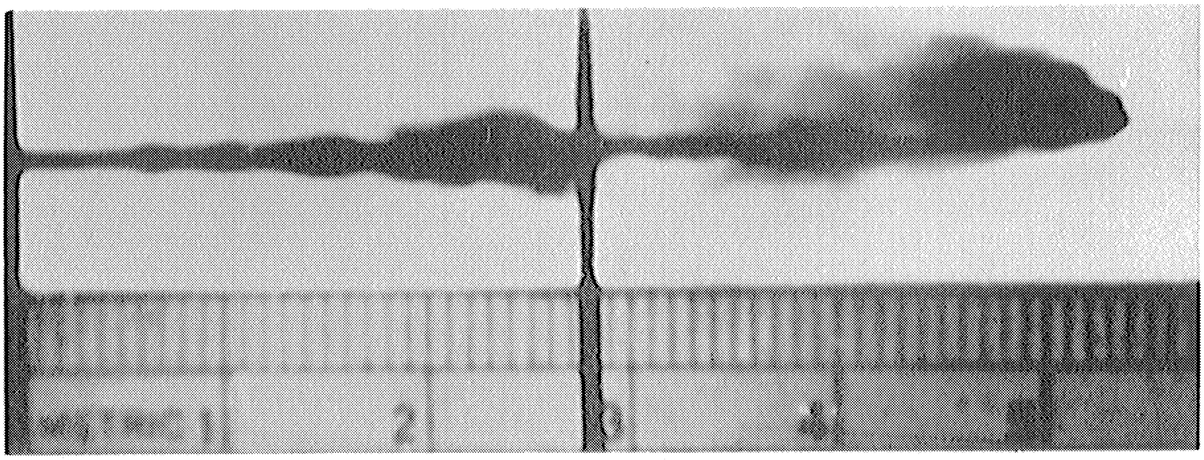


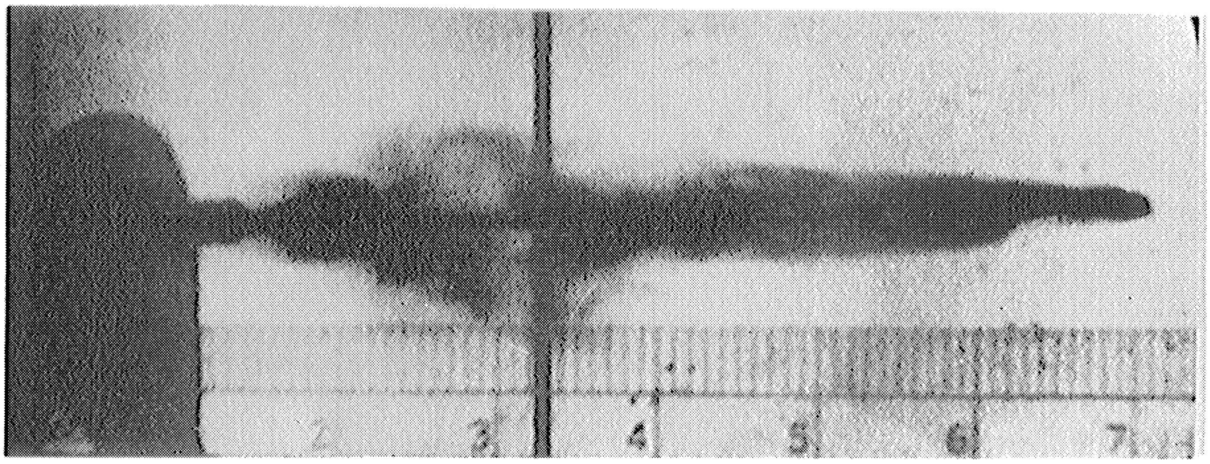
Fig. 3. Repeating Water Gun Device Including Remote Control, Motor Drive, and Vacuum Tank 2767



TYPE I, VELOCITY = 223 m/s



TYPE 2, VELOCITY = 322 m/s



TYPE 3, VELOCITY = 522 m/s

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Fig. 4. Typical Jets from Water Gun

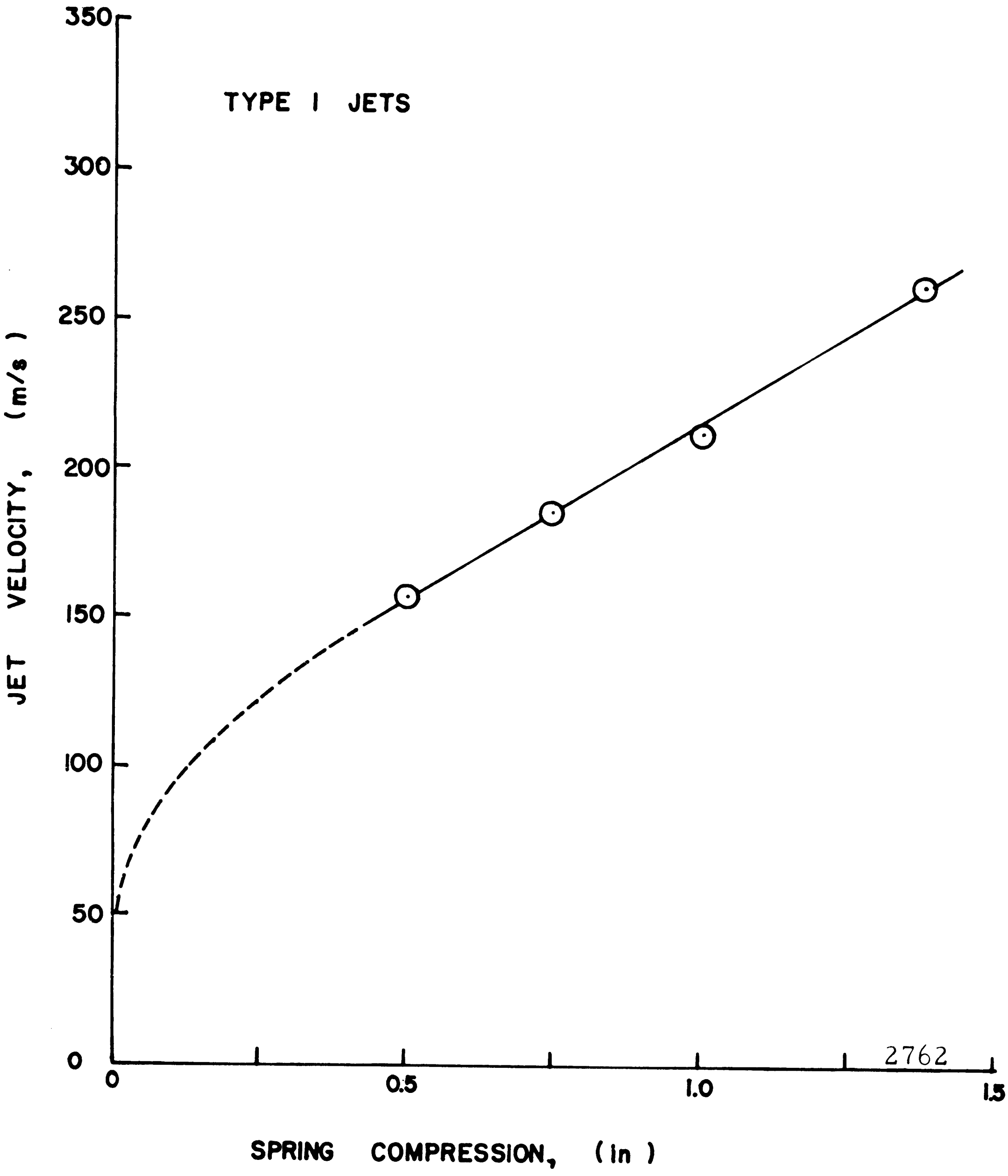


Fig. 5. Effect of Spring Compression on Water Jet Velocity

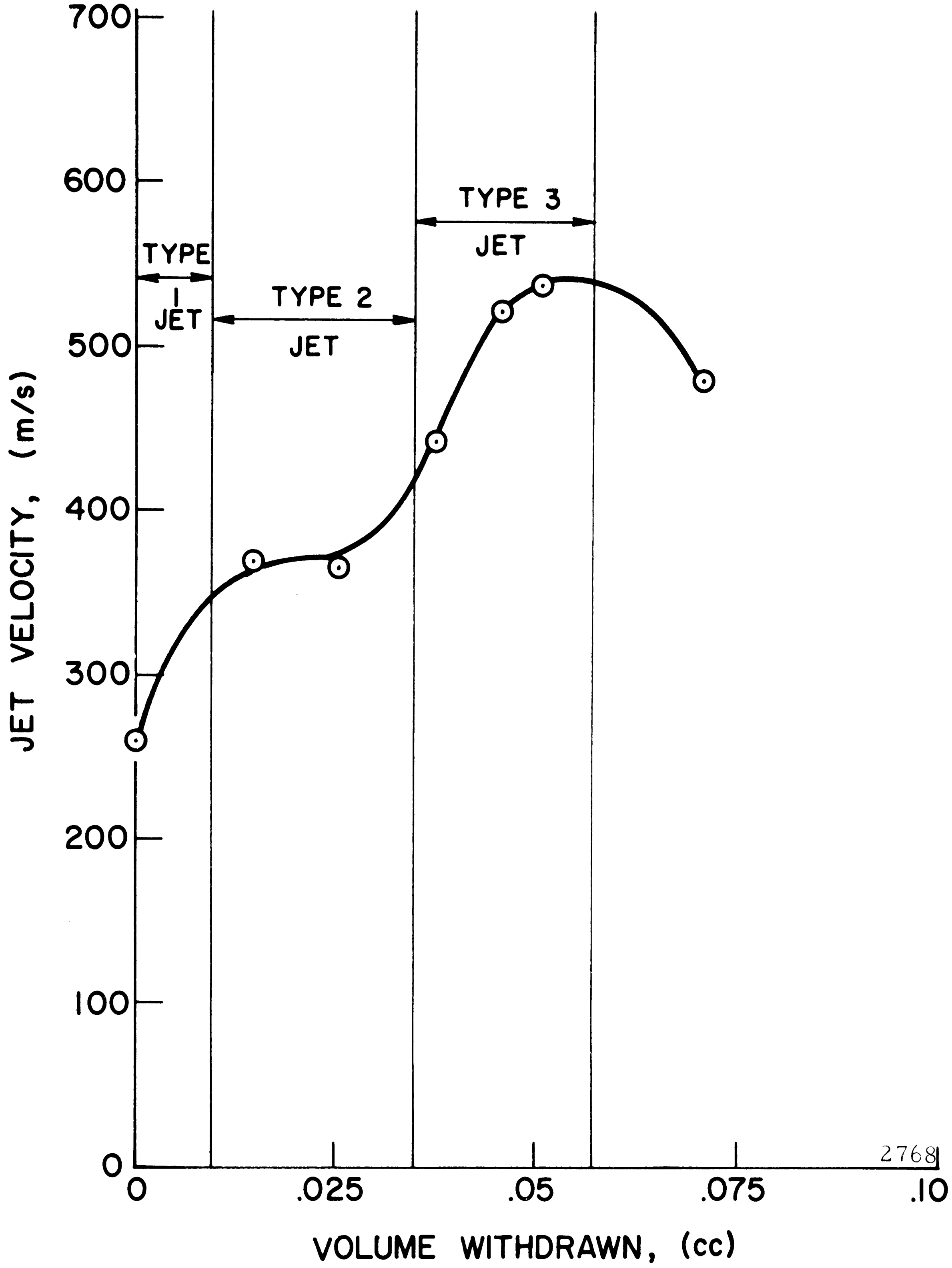


Fig. 6. Effect of Meniscus Withdrawal on Water Jet Velocity and Shape