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# STABILITY OF A VISCOUS JET - NON - NEWTONIAN LIQUIDS

By
R. E. Phinney
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7 MAY 1971

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The breakup distance for CMC solutions is compared to the known properties of Newtonian jets, as well as theoretical and experimental results for non-Newtonian fluids from other sources.

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An experimental study of the stability of a non-Newtonian liquid jet was performed at the Naval Ordnance Laboratory.

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By direction

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## SYMBOLS

| | |
|---|---|
| $A_i$, $B_i$ | Coefficients in curve fit |
| C | Polymer concentration |
| D | Nozzle diameter |
| L | Jet breakup length |
| M | Molecular weight |
| $N_{e\ell}$ | Elasticity number, $\lambda\mu_o/\rho D^2$ |
| n | Summation index |
| $n'$ | Logarithmic slope index of stress-strain rate curve |
| $\Delta p$ | Pressure drop through nozzle |
| $\Delta p'$ | Pressure end effect correction |
| $\Delta p_c$ | Pressure drop correction for end effect |
| $\Delta p_m$ | Measured pressure drop |
| R | Gas constant |
| $Re'$ | Reynolds number |
| T | Absolute temperature |
| U | Mean exit velocity |
| We | Weber number (W used in Table IV), $\rho DU^2/\sigma$ |
| Z | Ohnesorge number, $\mu/\sqrt{\rho\sigma D}$ |
| z | Molecular weight distribution parameter in relaxation time theory |
| $\dot{\gamma}$ | Strain rate |
| $\lambda$ | $1/\tau$ |
| $\mu_a$ | Apparent viscosity coefficient |
| $\mu_o$ | Viscosity coefficient at very low shear |
| $\mu_\infty$ | Viscosity coefficient at very high shear |
| $\rho$ | Fluid density |
| $\sigma$ | Surface tension |
| $\tau$ | Characteristic time or "relaxation time" |

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# INTRODUCTION

A great deal of both theoretical and experimental work has been done on the stability of a jet of Newtonian liquid into an atmosphere of relatively low density. Some of the work dates back to the beginning of this century. Grant and Middleman give a good, fairly recent, survey of this work in reference 1. Very early the parameter $L/D\sqrt{We}$ was identified as the factor that controls the breakup at low speeds where the effect of the ambient fluid is negligible. The ambient fluid was recognized as a destabilizing influence which produces a maximum in the breakup length - exit velocity curve, and a decreasing length with velocities about this critical value. Beyond this qualitative understanding of the influence of the ambient fluid, there remain many questions, primarily due to a lack of a comprehensive theoretical framework into which to fit the existing experimental data.

The extension that concerns us here is that introduced by using a non-Newtonian fluid in the jet. This question is prompted by the observation that many very viscous fluids, especially those of long chain organic molecules, have non-Newtonian behavior. Kroesser and Middleman (ref. 2) have considered a problem similar to this. Assuming as a theoretical model a Maxwell fluid (which is described by a single relaxation time), they find a reduction in stability due to the viscoelastic effects. In their experimental tests, a solution of polyisobutylene in Tetralin was used. The fluid was estimated to be operating in a region where the strain rate of the disturbances was low enough that the behavior was pseudo-Newtonian and the inclusion was that the measured decrease in stability was due to the elastic behavior (which produced normal stresses and a large expansion at the jet exit).

The present approach is somewhat different than in reference 2. Our interest is focused on a fluid which has a high enough polymer concentration that it shows non-Newtonian behavior, in that its stress-strain rate relation is definitely not linear, but where the concentration is low enough that no elastic effects are present. The approach is to investigate to what extent the new results can be interpreted in terms of the well-known Newtonian case. As a consequence, it is not necessary to adopt a particular mathematical model for the variation of viscosity since it is measured for the range of interest. Also, no attempt is made to generalize the theory since it is intended to explore to what extent the existing theory can be used.

## PREVIOUS RESULTS

The low-speed portion of the breakup curve is well understood since there are both theoretical and many experimental results, and they agree. A good summary of previous work for a Newtonian fluid is given by Grant and Middleman, reference 1. As the speed increases, the effects of the ambient fluid become more important and three new parameters, ambient density, viscosity, and relative velocity, are introduced. The ambient fluid reduces the stability, which causes a peak in the breakup length-exit velocity curve. Since the stability theory becomes even more complex when the ambient effects are introduced, there have been no theoretical results to date. The matter is further complicated by the fact that the mode of instability may change near the peak, or may even be different as some parameter of the ambient fluid changes. This lack of theoretical results has left the interpretation of the experimental data in confusion. Most of the experimental data in the literature are for standard atmospheric conditions surrounding the jet. Fenn and Middleman (ref. 3) have a systematic set of experiments investigating the effect of changes in ambient density, but are unable to solve the corresponding mathematical equations to provide a theoretical comparison.

In a previous paper (ref. 4), an electrical method for measuring the breakup length is described and applied to a Newtonian fluid. The data compare well with previous experiments in which the breakup length is recorded photographically. The apparatus and technique described in reference 4 are applied here to a non-Newtonian fluid (carboxymethylcellulose, CMC, in water with table salt added to increase electrical conductivity).

Non-Newtonian fluids are frequently characterized by a power law relation between stress and strain rate, which usually works over a restricted, but often large range of shear rate. This relationship overlooks what turns out to be an essential feature. Namely, it is known that at both low and high shear rates these fluids usually have pseudo-Newtonian tails with apparent viscosities, $\mu_o$ and $\mu_\infty$, respectively. For an up-to-date discussion concerning the viscosity of polymer solutions, see references 5 and 6, together with their cited references. Frequently, the low shear viscosity, $\mu_o$, is much larger than $\mu_\infty$. To see that $\mu_o$ is important even if the flow at the jet exit is well into the non-Newtonian region, the following argument can be used: When the ambient conditions can be neglected, the velocity profile in the jet quickly becomes uniform after the exit. The uniform velocity profile implies no shear stress so that the only stresses that exist are those due to the small disturbance velocities themselves. These disturbances have such low shear rates that they are often in the pseudo-Newtonian region though the flow in the nozzle obviously is not.

Although some effort has been made in the past to find an analytic description for the viscosity behavior of a non-Newtonian fluid, see references 5 and 6, it is not necessary for us to use this since we intend to relate the breakup characteristics to the experimentally determined values. Also, the nozzle flow velocity is measured (not calculated from the viscosity) experimentally so that the apparent viscosity can be determined from it.

## EXPERIMENTAL PROGRAM

A complete description of the apparatus is given in reference 4 and the important details are given below. The supply system for the various nozzles consisted of a high-pressure cylinder with a polyurethane piston which is driven by compressed air. The piston was found to cause no measurable pressure drop and showed no signs of sticking or chattering. The supply system was shock-mounted and the supply pipe diameters were large so as to reduce the input disturbance level to the nozzle.

All nozzles were constructed of glass capillary tubing to insure a smooth interior surface and to permit the measurement of diameter along their entire length. The orifice plates were constructed of stainless steel shim stock and the hole diameter was measured in four different directions to insure that the holes were circular. The dimensions of both the pipes and orifices are given in Table I.

The electrical system used to measure breakup distance is similar to that of reference 7. Electrical conduction through the jet operates a gate circuit which in turn measures the percentage of the time that the jet is broken. The breakup distance is defined in this study to be the point where the jet is broken 50 percent of the time. On the basis of a few measurements, it was found that the probability for breaks occurring in the jet is nearly Gaussian, which implies that the 50 percent point is also the most probable position for new breaks to start.

The solutions used were mixtures of high molecular weight, (high viscosity) carboxymethylcellulose (CMC) with water to give the desired viscosity, and with table salt added to give the conductivity necessary to operate the electrical circuits. The density was 1.04 $gm/cm^3$ for all solutions, except No. 117 for which it was 1.08. The other physical characteristics of the test solutions are given in Table II.

The mass flow rate was determined for each nozzle as a function of pressure by collecting and measuring the jet output for a measured time. From these measurements, the apparent viscosity and shear rate can be calculated.

As is pointed out in Chapter 5 of reference 8, if the pipe flow is laminar and time independent, then a universal curve is produced for each fluid if the apparent viscosity is plotted versus the apparent shear rate. If the tube is relatively short, then an end correction must be applied to the measured pressure drop as in the case of Newtonian flow. This problem is considered in detail later. The apparent shear rate is defined as, $\dot{\gamma}$,

$$\dot{\gamma} = 8U/D \qquad (1)$$

which is the shear rate at the wall for a Newtonian fluid. The corresponding value of the apparent viscosity, $\mu_a$, is

$$\mu_a = \left(\frac{\Delta pD}{4L}\right) / \left(\frac{8U}{D}\right) \qquad (2)$$

Reference 7 (page 30) points out that the theoretically interesting relation between local shear rate and local stress level can be obtained from the "apparent" values through a prescribed manipulation, provided a sufficient range of the curve has been measured. For convenience, however, the data will be retained in terms of the apparent values since they are defined through the measurable quantities such as U, D, and L.

One further simplification can be made before the fluid data is presented. It has been found (see ref. 5) that for dilute polymer solutions, the effect of concentration upon viscosity can be presented in a convenient nondimensional form. Strictly speaking, the method of reference 5 should be applied to the local stress and strain rate data, but we will use the method with the apparent values. The essence of reference is that there are three parameters, $\mu_o$, $\mu_\infty$, and $\tau$, (which are functions of concentration) which allow all the viscosity data to be presented as a universal curve of $(\mu_a - \mu_\infty)/(\mu_o - \mu_\infty)$ vs $\tau\dot{\gamma}$. This should correlate all data for all the dilute polymer solutions, and all shear rates, $\dot{\gamma}$. The data for the CMC solutions are given in Figure 1, while the best fit values of $\mu_o$ and $\mu_\infty$ are given in Figure 2. The symbols are defined in Table III. Data were taken over as broad a range of shear rates as practical with the cylindrical nozzles. A Brookfield viscometer was used to help fill out the low shear rate tail of the curve that defines $\mu_o$. The parameter, $\tau$, has the dimensions of time, and can be called a characteristic time or a relaxation time. Figure 3 shows the best fit values of $\tau$ as obtained from the viscosity data, as well as a theoretical estimate of $\tau_B$ from the theory of Bueche (see ref. 5 or 6)

$$\tau_B = \frac{12}{\pi^2} \frac{\mu_o M}{CRT} \qquad (3)$$

where M is the mean molecular weight of the polymer, C is its concentration, $\mu_o$ is the zero shear rate limiting value of the viscosity shown in Figure 2, R is the universal gas constant, and T is the absolute temperature. As discussed in reference 2, the theories used to calculate relaxation time are not very sophisticated nor very accurate, but the different theories do seem to agree in broad terms, and they do provide a convenient guideline for comparison. In the absence of experimental data, reference 2 uses equation (3) to calculate $\tau$.

In addition to using the flow rate curves to define the fluid properties, they were used as velocity calibration curves for the nozzles. This technique was used for both the nozzles and the orifices since it is inconvenient to intersperse weight flow and jet breakup measurements, and since the supply pressure is monitored during all tests.

Although it is conceptually very simple to use the pressure velocity curves as velocity calibrations, there are some practical problems. The primary problem is to obtain a curve fit of sufficient accuracy over a broad range of pressure and velocity. The following method appeared to be a good balance between accuracy and needed computer time.

First, the nozzle pressure drop, flow-rate data were correlated using a least squares curve fit of the form;

$$\ln\left(\frac{D\Delta p_c}{4L}\right) = \sum_{i=1}^{n} A_i \left[\ln\left(\frac{8U}{D}\right)\right]^{i-1} \qquad (4)$$

where the $A_i$'s were undetermined coefficients and $\Delta p_c$ was the pressure drop corrected for end loss effects, i.e.,

$$\Delta p_c = \Delta p_m - \Delta p' \qquad (5)$$

where

$$\Delta p' = C(\rho U^2/2) \qquad (6)$$

and where C depends upon the local value of the slope of the ln $(D\Delta p_c/4L)$ vs $\ln(8U/D)$ curve (see refs. 4 and 8). In the process of taking length breakup data, it was necessary to determine U from the above relationships between $\Delta p_m$ and U. This was done, using a "false position" iteration method (ref. 9), to solve for the roots of the equation,

$$f(U) = 0 \qquad (7)$$

where

$$f(U) = \ln\left(\frac{D\Delta p_m}{4L}\right) - \ln\left[\frac{D}{4L}\left(\frac{1}{2}C\rho U^2 + \Delta p_c\right)\right] \qquad (8)$$

and

$$Re' = \rho UD/\left[(D\Delta p_c/4L)/(8U/D)\right] \tag{9}$$

Usually four to ten iterations were needed to converge to a solution for U accurate to four figures.

For the orifice data, a pressure drop average velocity least squares curve was obtained in the form

$$U = \sum_{i=o}^{n} B_i(\Delta p_m)^i \tag{10}$$

a Reynolds number, Re′, was obtained by making use of equation (4), the measured pressure drop, $\Delta p_m$, and the calculated mean velocity, U, from equation (10).

$$Re' = \rho UD/\mu_a \tag{11}$$

where

$$(D\Delta p_c/4L)/(8U/D) \tag{12}$$

or

$$\mu_a = \exp\left[A_1 + (A_2-1)\ln(8U/D) + \sum_{i=3}^{n} A_i \ln(8U/D)^{i-1}\right] \tag{13}$$

This gives a Reynolds number for the orifice that is equivalent to the nozzle Reynolds number. The error of all the correlations was of the order of five percent or less.

## RESULTS

As discussed previously, the low-speed portion of the breakup length-exit velocity curve has been extensively studied for Newtonian fluids. It is found that $L/D\sqrt{We}$ is constant for each nozzle-fluid combination. Since this combination of parameters does not involve viscosity, there is no problem about carrying it over to the non-Newtonian case.

Experiment plus the analysis of Weber (ref. 10) both indicate that the parameter, $L/D\sqrt{We}$, should be a function of the viscosity of the jet through the parameter, Z. All the complications of the non-Newtonian case come in the definition and use of the parameter, Z. We observed that even if the exit flow is well into the non-Newtonian region, the amplifying disturbances are pseudo-Newtonian. Hence, the jet stability should depend (to a large extent) upon the asymptotic viscosity at very low shear rate, $\mu_o$. In Figure 4 is seen the result of plotting $L/D\sqrt{We}$ vs $Z_o$, where

$Z_o = \mu_o/\sqrt{\sigma \rho D}$. Note that each point in Figure 4 represents a fluid-jet combination for which a series of tests were run (the experimental results are tabulated in Appendix A). For each combination, a "best fit" slope is obtained and plotted in Figure 4 against the corresponding value of Z for the test.

It is seen that both the orifice and pipe data deviate from the Newtonian experiments to an increasing degree as $Z_o$ increases. This difference can be explained on the basis that the data for large $Z_o$ corresponds to high CMC concentrations for which the relaxation time is longer. With longer relaxation times, the product, $\tau\dot{\gamma}$, is larger, and, as is seen in Figure 1, the departure for the pseudo-Newtonian behavior may progress to the point where the unstable disturbances may not be characterized by $\mu_o$, but by a somewhat lower value of $\mu$, and, consequently, a lower value of Z. The above argument leads to the conclusion that the points with large Z should be shifted to the left along the Z scale, which is in the direction of the Newtonian data.

An empirical relationship between the exit shear rate and that of the disturbances can be introduced to account for this shift in Z. Through the flow curve in Figure 1, the shear rate, $\dot{\gamma}$, characteristic of the disturbances can be found from the value of $\mu$ necessary to shift the points in Figure 4 back to the Newtonian curve. It is found that this shear rate is on the order of $10^{-4}$ times less than the maximum shear rate at the nozzle exit.

An alternate way to analyze the results is to compare them to Kroesser's theory (ref. 2). He claims that $\mu$ is close enough to $\mu_o$ that only $Z_o$ need be considered. The effect to be expected is that the viscoelasticity destabilizes the jet, shortening L. He looks for a shift in the vertical direction in Figure 4, instead of in the horizontal. When the data are presented in coordinates suitable to Kroesser's theory, we get the plot of Figure 5, which correlates the data reasonably well.

Because of a lack of data concerning the fluid properties used in reference 2, it is difficult to verify his conclusions concerning the use of $\mu_o$, or to attempt a closer correlation of the two sets of data. One might expect that what Kroesser terms viscoelasticity (and elasticity number), and what we call non-Newtonian behavior are, in fact, the same phenomenon described by the parameter, $\tau$, which is either a relaxation time or a characteristic time, depending upon the point of view.

One area that was not explored in any detail, in either reference 2 or the present study, is the magnitude and the effect on stability of normal stresses in the fluid. Kroesser measured the effective jet diameter some distance after the exit, and used this in the data reduction in place of the jet exit diameter.

He found effective diameters almost three times the exit diameter in some cases. In our study, the diameter correction was not made because it was not measured and no empirical correlations exist. However, the change appeared to be small for all cases that were tested. Diameter changes smaller than those measured by Kroesser should have been obvious in the present experiments if they existed.

A useful set of tests that, unfortunately, were not included in the present series, is a variation in nozzle length. Length would have no effect on a Newtonian fluid, but would produce different levels of normal stress at the exit in elastic fluids.

Appendix A includes the data presented in the figures. In addition, this appendix also includes data around the maximum breakup distance, as well as beyond the peak. These data are made available in the hopes that a method will be found to correlate them. At the present time, no theoretical framework exists in which to present the data, and, hence, it is not plotted in graphical form.

After this report was largely completed, the author became aware of references 11 and 12. The theory developed in reference 11 agrees with Kroesser and Middleman, reference 2, in predicting that the effect of viscoelasticity should be to destabilize the jet. The experiments of references 11 and 12 show photographs of viscoelastic jets that contradict theory and the experiments of reference 2. The pictures show that the jets begin to break up as Newtonian jets do, with axisymmetric disturbances of increasing amplitude. When the disturbances become large, it is found that the small filaments connecting droplets do not break as they do with Newtonian fluids. This filament remains intact far beyond the point at which the equivalent Newtonian jet would break. In other words, instead of being less stable as predicted, the viscoelastic fluids could be interpreted as being more stable. The theory and experiments do not necessarily contradict each other, however, since at the point where the filaments form the disturbances are far past the infinitesimal level assumed by the theory. In addition, amplification rates are not measured in the experiments so that a direct check of the theory is not available.

The interpretation of the present experiments is somewhat confused by references 11 and 12. Since photographs were not taken with the present experiments, the long filaments connecting the droplets prior to breakup were not observed. It must be assumed that the filaments were present, although they were not observed directly. It is probable that the electrical apparatus that was used in the present experiments would count the filament as a broken jet instead of continuous. The reason for this is that the electrical resistance of the filament is many times greater than the jet since its diameter is much smaller.

The basic problem is that if the gate is made too sensitive, then it responds to strong currents and other noise-type inputs. It is also hazardous to increase the signal voltage from the jet by increasing the power supply voltage.

The present experiments can be interpreted as follows: If the term "broken" is taken to mean a large reduction in cross-sectional area of the jet, instead of the final disruption of the small filament connection droplets, then the stability of viscoelastic jets is more easily identified with the theory and with the Newtonian results.

The complete explanation for apparent disagreement between the present results and reference 2 on one hand, and references 11 and 12 on the other, remains to be cleared up.

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## TABLE I

## DIMENSIONS OF PIPES AND ORIFICES

| Nozzle | Diameter | Length | Material |
|---|---|---|---|
| 1 | 0.125 | 17.845 | Glass |
| 2 | 0.05041 | 7.43 | Glass |
| 3a | 0.1029 | <0.005 | Stainless |
| 2a | 0.0664 | <0.005 | Stainless |
| 1a | 0.0372 | <0.005 | Stainless |

## TABLE II

## FLUID PROPERTIES

| Sol. No. | $C \times 10^3$ gm/gm | $\sigma$ dynes/cm | $\mu_o$ poise | $\mu_\infty$ poise | $\tau \times 10^3$ sec |
|---|---|---|---|---|---|
| 102 | 7.93 | 73.8 | 2.3 | 0.060 | 8.095 |
| 103 | 2.64 | 69.5 | 0.092 | 0.022 | 1.030 |
| 107 | 2.64 | 75.4 | 0.1 | 0.021 | 0.567 |
| 109 | 7.94 | 75.05 | 1.5 | 0.052 | 6.07 |
| 110 | 10.57 | 73.95 | 6.2 | 0.051 | 18.89 |
| 111 | 6.08 | 73.55 | 0.6 | 0.032 | 1.889 |
| 112 | 5.81 | 75.0 | 0.44 | 0.039 | 1.790 |
| 115 | 8.98 | 74.0 | 2.8 | 0.058 | 9.71 |
| 117 | 10.85 | 76.0 | 5.6 | 0.058 | 9.71 |

TABLE III SYMBOLS

| SOLUTION NUMBER | SYMBOL | NOZZLE # 1 SYMBOL | NOZZLE # 2 SYMBOL | ORIFICE # 3 SYMBOL | ORIFICE # 4 SYMBOL | ORIFICE # 5 SYMBOL |
|---|---|---|---|---|---|---|
| 102 | ○ | ◒ | ◓ | | ◓ | |
| 103 | □ | ⬓ | ⬒ | | | |
| 107 | △ | ▲ | ▲ | ▲ | ▲ | |
| 109 | ▽ | ▼ | ▼ | | | ▼ |
| 110 | ◇ | ⬙ | ⬘ | | | ⬖ |
| 111 | ⬡ | ⬢ | ⬢ | | ⬢ | ⬢ |
| 112 | ◁ | ◀ | ◀ | | ◀ | ◀ |
| 115 | ▷ | ▶ | ▶ | | ▶ | ▶ |
| 117 | ⬦ | ⬙ | ⬘ | | ⬘ | ⬖ |

## Table IVa

```
                         SOLUTION NUMBER  102

                         NOZZLE NUMBER      1

PRESS (PSI)          L/C           U (CM/SEC)          W

 2.730E 01        3.596E 02        4.489E 02       3.553E 02
 1.860E 01        2.349E 02        2.743E 02       1.326E 02
 2.230E 01        2.782E 02        3.396E 02       2.034E 02
 2.550E 01        3.278E 02        4.089E 02       2.948E 02
 2.980E 01        3.910E 02        5.060E 02       4.519E 02
 4.000E 01        4.819E 02        7.142E 02       8.595E 02
 4.600E 01        4.669E 02        8.321E 02       1.221E 03
 5.600E 01        4.567E 02        1.011E 03       1.803E 03
 6.800E 01        4.545E 02        1.197E 03       2.529E 03
```

## Table IVb

```
                         SOLUTION NUMBER  102

                         ORIFICE NUMBER   2a

PRESS (PSI)          L/C           U (CM/SEC)          W

 8.000E 00        3.918E 02        6.[illegible]16E 02       4.480E 02
 1.060E 01        4.701E 02        7.845E 02       5.764E 02
 1.300E 01        5.378E 02        8.635E 02       6.983E 02
 1.540E 01        5.830E 02        9.364E 02       8.213E 02
 1.840E 01        6.493E 02        1.020E 03       9.739E 02
 2.240E 01        7.381E 02        1.118E 03       1.171E 03
 2.550E 01        8.089E 02        1.186E 03       1.317E 03
 2.920E 01        8.285E 02        1.258E 03       1.482E 03
 4.600E 01        1.125E 03        1.402E 03       2.116E 03
 5.600E 01        1.175E 03        1.623E 03       2.468E 03
 6.900E 01        1.214E 03        1.744E 03       2.848E 03
 7.700E 01        1.253E 03        1.959E 03       3.594E 03
 8.700E 01        1.301E 03        2.217E 03       4.605E 03
```

## Table IVc

SOLUTION NUMBER 103

NOZZLE NUMBER 1

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 1.280E 01 | 4.200E 01 | 5.267E 02 | 5.170E 02 |
| 1.480E 01 | 4.440E 01 | 5.631E 02 | 6.554E 02 |
| 3.800E 00 | 1.011E 02 | 1.797E 02 | 6.016E 01 |
| 5.000E 00 | 9.025E 01 | 2.294E 02 | 9.809E 01 |
| 6.500E 00 | 5.606E 01 | 2.614E 02 | 1.582E 02 |
| 7.500E 00 | 5.523E 01 | 3.220E 02 | 2.053E 02 |
| 8.500E 00 | 5.602E 01 | 3.704E 02 | 2.557E 02 |
| 9.500E 00 | 5.441E 01 | 4.076E 02 | 3.096E 02 |
| 3.000E 00 | 8.010E 01 | 1.460E 02 | 3.972E 01 |
| 3.500E 00 | 8.843E 01 | 1.577E 02 | 5.207E 01 |
| 4.500E 00 | 1.088E 02 | 2.087E 02 | 8.119E 01 |
| 4.000E 00 | 1.037E 02 | 1.680E 02 | 6.582E 01 |
| 5.500E 00 | 8.762E 01 | 2.503E 02 | 1.167E 02 |
| 7.000E 00 | 5.524E 01 | 3.117E 02 | 1.811E 02 |

## Table IVd

SOLUTION NUMBER 107

ORIFICE NUMBER 1a

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 3.000E 01 | 2.903E 02 | 1.525E 03 | 1.260E 03 |
| 6.100E 01 | 3.844E 02 | 2.015E 03 | 2.199E 03 |
| 4.500E 01 | 3.118E 02 | 1.769E 03 | 1.696E 03 |
| 7.000E 01 | 3.844E 02 | 2.231E 03 | 2.697E 03 |
| 1.050E 02 | 4.194E 02 | 2.619E 03 | 3.706E 03 |
| 1.310E 02 | 4.785E 02 | 2.924E 03 | 4.632E 03 |
| 1.680E 02 | 5.027E 02 | 3.212E 03 | 5.944E 03 |
| 2.040E 02 | 5.430E 02 | 3.740E 03 | 7.179E 03 |
| 2.430E 02 | 5.833E 02 | 3.950E 03 | 8.459E 03 |
| 3.080E 02 | 6.263E 02 | 4.493E 03 | 1.046E 04 |
| 3.500E 02 | 6.559E 02 | 4.651E 03 | 1.172E 04 |
| 3.950E 02 | 6.935E 02 | 4.920E 03 | 1.311E 04 |
| 4.470E 02 | 7.231E 02 | 5.245E 03 | 1.490E 04 |
| 4.960E 02 | 7.339E 02 | 5.587E 03 | 1.651E 04 |

Table IVe

SOLUTION NUMBER 103

NOZZLE NUMBER 2

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 1.650E 01 | 8.531E 01 | 3.908E 02 | 1.147E 02 |
| 1.900E 01 | 9.324E 01 | 4.468E 02 | 1.500E 02 |
| 2.100E 01 | 9.026E 01 | 4.913E 02 | 1.814E 02 |
| 2.310E 01 | 8.431E 01 | 5.479E 02 | 2.174E 02 |
| 2.540E 01 | 7.737E 01 | 5.886E 02 | 2.604E 02 |
| 2.750E 01 | 7.340E 01 | 6.327E 02 | 3.008E 02 |
| 2.970E 01 | 6.943E 01 | 6.729E 02 | 3.402E 02 |
| 6.500E 00 | 4.073E 01 | 1.414E 02 | 1.502E 01 |
| 8.000E 00 | 5.462E 01 | 1.785E 02 | 2.393E 01 |
| 9.600E 00 | 6.551E 01 | 2.189E 02 | 3.602E 01 |
| 1.100E 01 | 6.748E 01 | 2.539E 02 | 4.844E 01 |
| 1.280E 01 | 7.441E 01 | 2.986E 02 | 6.709E 01 |
| 1.460E 01 | 8.333E 01 | 3.442E 02 | 8.902E 01 |
| 1.710E 01 | 9.325E 01 | 4.042E 02 | 1.228E 02 |
| 1.750E 01 | 9.325E 01 | 4.132E 02 | 1.283E 02 |
| 1.840E 01 | 9.424E 01 | 4.334E 02 | 1.411E 02 |
| 1.800E 01 | 9.424E 01 | 4.244E 02 | 1.354E 02 |
| 1.960E 01 | 9.324E 01 | 4.602E 02 | 1.591E 02 |
| 2.100E 01 | 9.126E 01 | 4.913E 02 | 1.814E 02 |
| 3.000E 01 | 6.745E 01 | 6.783E 02 | 3.457E 02 |
| 3.500E 01 | 5.753E 01 | 7.673E 02 | 4.424E 02 |
| 4.200E 01 | 5.158E 01 | 8.877E 02 | 5.921E 02 |
| 4.500E 01 | 5.158E 01 | 9.381E 02 | 6.612E 02 |
| 5.000E 01 | 5.753E 01 | 1.026E 03 | 7.903E 02 |

## Table IVf

SOLUTION NUMBER 107

NOZZLE NUMBER 2

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 1.170E 01 | 5.815E 01 | 2.351E 02 | 3.878E 01 |
| 1.450E 01 | 8.077E 01 | 2.937E 02 | 6.052E 01 |
| 1.720E 01 | 9.385E 01 | 3.506E 02 | 8.624E 01 |
| 2.020E 01 | 1.071E 02 | 4.110E 02 | 1.185E 02 |
| 2.280E 01 | 1.155E 02 | 4.612E 02 | 1.492E 02 |
| 2.600E 01 | 1.188E 02 | 5.225E 02 | 1.915E 02 |
| 2.900E 01 | 1.182E 02 | 5.796E 02 | 2.357E 02 |
| 2.700E 01 | 1.190E 02 | 5.416E 02 | 2.057E 02 |
| 2.540E 01 | 1.192E 02 | 5.110E 02 | 1.832E 02 |
| 2.440E 01 | 1.190E 02 | 4.919E 02 | 1.697E 02 |
| 2.300E 01 | 1.165E 02 | 4.650E 02 | 1.517E 02 |
| 1.360E 01 | 7.819E 01 | 2.748E 02 | 5.298E 01 |
| 9.000E 00 | 5.184E 01 | 1.743E 02 | 2.131E 01 |
| 7.000E 00 | 3.238E 01 | 1.293E 02 | 1.172E 01 |
| 7.500E 00 | 4.413E 01 | 1.413E 02 | 1.400E 01 |
| 8.100E 00 | 5.088E 01 | 1.544E 02 | 1.672E 01 |
| 3.200E 01 | 1.242E 02 | 6.354E 02 | 2.831E 02 |
| 3.600E 01 | 1.293E 02 | 7.045E 02 | 3.481E 02 |
| 3.700E 01 | 1.272E 02 | 7.216E 02 | 3.653E 02 |
| 4.300E 01 | 1.343E 02 | 8.233E 02 | 4.754E 02 |
| 5.000E 01 | 1.418E 02 | 9.298E 02 | 6.195E 02 |
| 5.600E 01 | 1.464E 02 | 1.037E 03 | 7.543E 02 |
| 6.000E 01 | 1.500E 02 | 1.097E 03 | 8.435E 02 |
| 7.000E 01 | 1.591E 02 | 1.242E 03 | 1.083E 03 |
| 8.000E 01 | 1.698E 02 | 1.384E 03 | 1.344E 03 |
| 9.200E 01 | 1.825E 02 | 1.550E 03 | 1.685E 03 |
| 1.000E 02 | 1.960E 02 | 1.658E 03 | 1.929E 03 |
| 1.220E 02 | 2.240E 02 | 1.927E 03 | 2.605E 03 |
| 1.350E 02 | 2.482E 02 | 2.079E 03 | 3.030E 03 |
| 1.510E 02 | 2.630E 02 | 2.260E 03 | 3.583E 03 |
| 1.690E 02 | 2.771E 02 | 2.459E 03 | 4.240E 03 |
| 1.900E 02 | 2.922E 02 | 2.684E 03 | 5.052E 03 |
| 2.150E 02 | 3.063E 02 | 2.933E 03 | 6.034E 03 |
| 2.370E 02 | 3.158E 02 | 3.139E 03 | 6.912E 03 |
| 2.650E 02 | 3.267E 02 | 3.394E 03 | 8.077E 03 |
| 3.060E 02 | 3.398E 02 | 3.752E 03 | 9.873E 03 |
| 3.350E 02 | 3.487E 02 | 3.996E 03 | 1.120E 04 |
| 3.940E 02 | 3.616E 02 | 4.475E 03 | 1.405E 04 |
| 4.560E 02 | 3.799E 02 | 4.940E 03 | 1.712E 04 |
| 5.000E 02 | 3.936E 02 | 5.254E 03 | 1.936E 04 |

## Table IVg

SOLUTION NUMBER 107

ORIFICE NUMBER 2a

| PRESS (PSI) | L/D | U (CM/SEC) | h |
|---|---|---|---|
| 7.600E 00 | 1.616E 02 | 1.017E 03 | 1.001E 03 |
| 1.040E 01 | 1.922E 02 | 1.069E 03 | 1.104E 03 |
| 1.340E 01 | 2.124E 02 | 1.122E 03 | 1.219E 03 |
| 1.600E 01 | 2.080E 02 | 1.169E 03 | 1.322E 03 |
| 1.670E 01 | 2.539E 02 | 1.181E 03 | 1.350E 03 |
| 2.200E 01 | 2.717E 02 | 1.274E 03 | 1.570E 03 |
| 2.500E 01 | 2.878E 02 | 1.326E 03 | 1.700E 03 |
| 2.950E 01 | 3.149E 02 | 1.402E 03 | 1.901E 03 |
| 3.200E 01 | 3.387E 02 | 1.444E 03 | 2.016E 03 |
| 3.900E 01 | 3.770E 02 | 1.558E 03 | 2.348E 03 |
| 5.000E 01 | 3.935E 02 | 1.732E 03 | 2.900E 03 |
| 6.100E 01 | 4.157E 02 | 1.897E 03 | 3.480E 03 |
| 7.500E 01 | 4.472E 02 | 2.097E 03 | 4.251E 03 |
| 9.500E 01 | 4.727E 02 | 2.362E 03 | 5.395E 03 |
| 1.340E 02 | 5.075E 02 | 2.817E 03 | 7.675E 03 |
| 1.630E 02 | 5.392E 02 | 3.109E 03 | 9.348E 03 |
| 1.920E 02 | 5.843E 02 | 3.367E 03 | 1.097E 04 |
| 2.450E 02 | 6.370E 02 | 3.770E 03 | 1.375E 04 |
| 3.080E 02 | 6.491E 02 | 4.172E 03 | 1.684E 04 |
| 3.500E 02 | 6.401E 02 | 4.419E 03 | 1.889E 04 |
| 3.750E 02 | 6.295E 02 | 4.567E 03 | 2.017E 04 |
| 4.000E 02 | 6.205E 02 | 4.718E 03 | 2.153E 04 |
| 4.580E 02 | 6.084E 02 | 5.106E 03 | 2.521E 04 |
| 4.930E 02 | 6.074E 02 | 5.378E 03 | 2.797E 04 |
| 2.630E 02 | 6.348E 02 | 3.892E 03 | 1.465E 04 |
| 2.950E 02 | 6.378E 02 | 4.094E 03 | 1.621E 04 |
| 3.320E 02 | 6.295E 02 | 4.314E 03 | 1.800E 04 |
| 3.540E 02 | 6.235E 02 | 4.443E 03 | 1.909E 04 |

## Table IVh

SOLUTION NUMBER 109

NOZZLE NUMBER 1

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 1.650E 01 | 1.699E 02 | 2.390E 02 | 9.917E 01 |
| 1.900E 01 | 2.041E 02 | 3.014E 02 | 1.577E 02 |
| 2.150E 01 | 2.411E 02 | 3.651E 02 | 2.313E 02 |
| 2.470E 01 | 2.822E 02 | 4.417E 02 | 3.386E 02 |
| 2.900E 01 | 3.201E 02 | 5.507E 02 | 5.262E 02 |
| 3.400E 01 | 3.164E 02 | 6.600E 02 | 7.560E 02 |
| 4.000E 01 | 3.579E 02 | 7.894E 02 | 1.081E 03 |
| 5.000E 01 | 3.609E 02 | 9.934E 02 | 1.713E 03 |
| 5.800E 01 | 3.217E 02 | 1.131E 03 | 2.218E 03 |
| 6.600E 01 | 3.112E 02 | 1.265E 03 | 2.779E 03 |
| 7.500E 01 | 3.040E 02 | 1.415E 03 | 3.473E 03 |
| 4.300E 01 | 3.210E 02 | 8.548E 02 | 1.268E 03 |
| 4.700E 01 | 3.449E 02 | 9.413E 02 | 1.538E 03 |
| 5.200E 01 | 3.573E 02 | 1.028E 03 | 1.834E 03 |
| 5.600E 01 | 3.593E 02 | 1.097E 03 | 2.087E 03 |
| 5.400E 01 | 3.585E 02 | 1.062E 03 | 1.959E 03 |
| 6.000E 01 | 3.469E 02 | 1.165E 03 | 2.353E 03 |
| 6.500E 01 | 3.272E 02 | 1.249E 03 | 2.706E 03 |
| 5.500E 01 | 3.397E 02 | 1.079E 03 | 2.022E 03 |
| 6.100E 01 | 3.397E 02 | 1.181E 03 | 2.422E 03 |
| 6.500E 01 | 3.408E 02 | 1.249E 03 | 2.706E 03 |
| 7.000E 01 | 3.280E 02 | 1.332E 03 | 3.079E 03 |
| 4.400E 01 | 3.017E 02 | 8.767E 02 | 1.334E 03 |
| 5.000E 01 | 3.337E 02 | 9.934E 02 | 1.713E 03 |
| 5.500E 01 | 3.401E 02 | 1.079E 03 | 2.022E 03 |
| 6.000E 01 | 3.329E 02 | 1.165E 03 | 2.353E 03 |
| 7.000E 01 | 3.104E 02 | 1.332E 03 | 3.079E 03 |
| 8.100E 01 | 2.972E 03 | 1.513E 03 | 3.971E 03 |
| 8.600E 01 | 2.952E 02 | 1.584E 03 | 4.355E 03 |
| 2.500E 01 | 2.599E 02 | 4.491E 02 | 3.500E 02 |
| 3.500E 01 | 3.228E 02 | 6.814E 02 | 8.058E 02 |
| 4.000E 01 | 2.970E 02 | 7.894E 02 | 1.081E 03 |
| 3.000E 01 | 3.087E 02 | 5.750E 02 | 5.738E 02 |
| 4.000E 01 | 3.062E 02 | 7.894E 02 | 1.081E 03 |
| 4.600E 01 | 2.793E 02 | 9.207E 02 | 1.471E 03 |
| 5.500E 01 | 2.752E 02 | 1.079E 03 | 2.022E 03 |

## Table IVi

SOLUTION NUMBER 109

NOZZLE NUMBER 2

| PRESS (PSI) | L/D | U (CM/SEC) | h |
|---|---|---|---|
| 2.700E 01 | 1.183E 02 | 2.332E 02 | 3.805E 01 |
| 3.500E 01 | 1.558E 02 | 3.448E 02 | 8.320E 01 |
| 4.500E 01 | 1.855E 02 | 4.942E 02 | 1.641E 02 |
| 5.500E 01 | 3.344E 02 | 6.278E 02 | 2.758E 02 |
| 6.500E 01 | 3.869E 02 | 7.540E 02 | 3.979E 02 |
| 7.500E 01 | 4.037E 02 | 8.821E 02 | 5.446E 02 |
| 8.200E 01 | 3.948E 02 | 9.728E 02 | 6.623E 02 |
| 9.400E 01 | 4.047E 02 | 1.112E 03 | 8.647E 02 |
| 1.050E 02 | 4.126E 02 | 1.229E 03 | 1.058E 03 |
| 1.180E 02 | 4.186E 02 | 1.367E 03 | 1.308E 03 |
| 1.300E 02 | 4.186E 02 | 1.493E 03 | 1.560E 03 |
| 1.350E 02 | 4.235E 02 | 1.545E 03 | 1.671E 03 |
| 1.440E 02 | 4.245E 02 | 1.639E 03 | 1.880E 03 |
| 1.680E 02 | 4.344E 02 | 1.852E 03 | 2.401E 03 |
| 1.870E 02 | 4.374E 02 | 2.010E 03 | 2.827E 03 |
| 2.250E 02 | 4.563E 02 | 2.314E 03 | 3.747E 03 |
| 2.700E 02 | 4.880E 02 | 2.658E 03 | 4.946E 03 |
| 3.150E 02 | 5.297E 02 | 2.961E 03 | 6.135E 03 |
| 3.540E 02 | 5.614E 02 | 3.196E 03 | 7.151E 03 |
| 4.060E 02 | 5.892E 02 | 3.497E 03 | 8.559E 03 |
| 5.100E 01 | 2.957E 02 | 5.699E 02 | 2.274E 02 |
| 6.100E 01 | 3.492E 02 | 7.033E 02 | 3.462E 02 |
| 8.100E 01 | 4.027E 02 | 9.598E 02 | 6.447E 02 |
| 6.500E 01 | 3.730E 02 | 7.540E 02 | 3.979E 02 |
| 7.100E 01 | 3.948E 02 | 8.306E 02 | 4.829E 02 |
| 8.000E 01 | 4.037E 02 | 9.468E 02 | 6.274E 02 |
| 7.400E 01 | 4.008E 02 | 8.692E 02 | 5.288E 02 |
| 9.100E 01 | 4.027E 02 | 1.079E 03 | 8.151E 02 |
| 9.800E 01 | 4.047E 02 | 1.154E 03 | 9.328E 02 |
| 1.150E 02 | 4.126E 02 | 1.335E 03 | 1.248E 03 |
| 1.260E 02 | 4.166E 02 | 1.451E 03 | 1.474E 03 |
| 3.500E 02 | 5.574E 02 | 3.173E 03 | 7.045E 03 |
| 3.850E 02 | 5.832E 02 | 3.377E 03 | 7.983E 03 |
| 4.100E 02 | 5.931E 02 | 3.520E 03 | 8.670E 03 |

## Table IVj

SOLUTION NUMBER 109

ORIFICE NUMBER 3a

| PRESS (PSI) | L/C | U (CM/SEC) | h |
|---|---|---|---|
| 4.500E 00 | 2.577E 02 | 6.228E 02 | 5.682E 02 |
| 7.000E 00 | 3.356E 02 | 6.885E 02 | 6.944E 02 |
| 1.070E 01 | 4.114E 02 | 7.837E 02 | 8.997E 02 |
| 1.510E 01 | 4.862E 02 | 8.938E 02 | 1.170E 03 |
| 1.960E 01 | 5.386E 02 | 1.003E 03 | 1.473E 03 |
| 2.450E 01 | 5.998E 02 | 1.118E 03 | 1.830E 03 |
| 2.950E 01 | 6.465E 02 | 1.231E 03 | 2.220E 03 |
| 3.000E 01 | 6.494E 02 | 1.242E 03 | 2.260E 03 |
| 4.100E 01 | 7.280E 02 | 1.476E 03 | 3.191E 03 |
| 5.000E 01 | 7.785E 02 | 1.654E 03 | 4.005E 03 |
| 6.000E 01 | 8.329E 02 | 1.837E 03 | 4.943E 03 |
| 6.000E 01 | 8.310E 02 | 1.837E 03 | 4.943E 03 |
| 8.000E 01 | 9.534E 02 | 2.163E 03 | 6.854E 03 |
| 1.000E 02 | 9.738E 02 | 2.440E 03 | 8.722E 03 |
| 1.240E 02 | 9.806E 02 | 2.717E 03 | 1.081E 04 |
| 1.510E 02 | 9.835E 02 | 2.967E 03 | 1.290E 04 |
| 1.700E 02 | 9.077E 02 | 3.113E 03 | 1.420E 04 |
| 1.880E 02 | 9.106E 02 | 3.234E 03 | 1.532E 04 |
| 2.050E 02 | 8.941E 02 | 3.336E 03 | 1.630E 04 |
| 2.250E 02 | 8.630E 02 | 3.447E 03 | 1.741E 04 |
| 2.500E 02 | 8.601E 02 | 3.581E 03 | 1.879E 04 |
| 3.000E 02 | 8.348E 02 | 3.880E 03 | 2.205E 04 |
| 3.650E 02 | 8.183E 02 | 4.464E 03 | 2.918E 04 |
| 1.150E 02 | 1.055E 03 | 2.619E 03 | 1.005E 04 |
| 1.390E 02 | 1.102E 03 | 2.863E 03 | 1.200E 04 |
| 1.610E 02 | 1.053E 03 | 3.047E 03 | 1.360E 04 |
| 1.800E 02 | 1.008E 03 | 3.182E 03 | 1.483E 04 |
| 1.550E 02 | 1.058E 03 | 3.000E 03 | 1.318E 04 |

Table IVk

SOLUTION NUMBER 110

NOZZLE NUMBER 1

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 2.480E 01 | 3.262E 02 | 2.285E 02 | 9.193E 01 |
| 2.700E 01 | 3.586E 02 | 2.665E 02 | 1.251E 02 |
| 2.900E 01 | 4.001E 02 | 3.033E 02 | 1.621E 02 |
| 3.200E 01 | 5.403E 02 | 3.600E 02 | 2.283E 02 |
| 4.000E 01 | 6.671E 02 | 5.105E 02 | 4.590E 02 |
| 4.500E 01 | 7.162E 02 | 6.053E 02 | 6.453E 02 |
| 5.100E 01 | 7.985E 02 | 7.111E 02 | 8.906E 02 |
| 5.800E 01 | 8.026E 02 | 8.391E 02 | 1.240E 03 |
| 6.600E 01 | 7.106E 02 | 9.792E 02 | 1.689E 03 |
| 7.200E 01 | 6.285E 02 | 1.070E 03 | 2.017E 03 |
| 5.000E 01 | 7.631E 02 | 6.432E 02 | 8.464E 02 |
| 5.700E 01 | 8.230E 02 | 8.205E 02 | 1.186E 03 |
| 5.500E 01 | 8.001E 02 | 7.837E 02 | 1.082E 03 |
| 6.200E 01 | 7.857E 02 | 9.143E 02 | 1.472E 03 |
| 7.100E 01 | 6.349E 02 | 1.055E 03 | 1.961E 03 |
| 8.900E 01 | 5.345E 02 | 1.229E 03 | 3.111E 03 |
| 1.030E 02 | 5.025E 02 | 1.543E 03 | 4.192E 03 |
| 1.200E 02 | 5.000E 02 | 1.746E 03 | 5.369E 03 |
| 8.000E 01 | 5.466E 02 | 1.192E 03 | 2.502E 03 |
| 1.340E 02 | 5.016E 02 | 1.909E 03 | 6.421E 03 |
| 1.550E 02 | 5.184E 02 | 2.148E 03 | 8.129E 03 |
| 1.700E 02 | 5.056E 02 | 2.315E 03 | 9.442E 03 |
| 2.100E 02 | 5.080E 02 | 2.711E 03 | 1.294E 04 |
| 2.250E 02 | 5.240E 02 | 2.839E 03 | 1.419E 04 |

## Table IV1

SOLUTION NUMBER 110

NOZZLE NUMBER 2

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 3.500E 01 | 1.583E 02 | 1.763E 02 | 2.207E 01 |
| 4.500E 01 | 2.591E 02 | 2.744E 02 | 5.350E 01 |
| 5.500E 01 | 3.819E 02 | 3.[illegible]27E 02 | 1.040E 02 |
| 6.500E 01 | 4.988E 02 | 4.[illegible]96E 02 | 1.703E 02 |
| 7.500E 01 | 5.958E 02 | 6.[illegible]46E 02 | 2.596E 02 |
| 9.100E 01 | 6.967E 02 | 7.752E 02 | 4.266E 02 |
| 1.100E 02 | 8.831E 02 | 9.[illegible]52E 02 | 6.894E 02 |
| 1.300E 02 | 8.819E 02 | 1.187E 03 | 9.936E 02 |
| 1.450E 02 | 8.283E 02 | 1.327E 03 | 1.291E 03 |
| 1.680E 02 | 7.538E 02 | 1.[illegible]50E 03 | 1.706E 03 |
| 1.880E 02 | 7.102E 02 | 1.735E 03 | 2.138E 03 |
| 2.170E 02 | 6.755E 02 | 1.965E 03 | 2.743E 03 |
| 2.550E 02 | 6.646E 02 | 2.261E 03 | 3.630E 03 |
| 3.100E 02 | 6.586E 02 | 2.[illegible]78E 03 | 5.095E 03 |
| 3.560E 02 | 6.606E 02 | 2.[illegible]81E 03 | 6.311E 03 |
| 4.450E 02 | 6.804E 02 | 3.505E 03 | 8.724E 03 |
| 4.000E 01 | 1.825E 02 | 2.252E 02 | 3.602E 01 |
| 4.[illegible]00E 01 | 3.229E 02 | 3.056E 02 | 6.633E 01 |
| 6.400E 01 | 4.809E 02 | 4.78[illegible]E 02 | 1.626E 02 |
| 7.600E 01 | 6.464E 02 | 6.220E 02 | 2.748E 02 |
| 8.800E 01 | 7.514E 02 | 7.430E 02 | 3.921E 02 |
| 9.600E 01 | 7.959E 02 | 8.294E 02 | 4.886E 02 |
| 1.080E 02 | 8.612E 02 | 9.420E 02 | 6.581E 02 |
| 1.190E 02 | 8.810E 02 | 1.077E 03 | 8.246E 02 |
| 1.240E 02 | 8.849E 02 | 1.12[illegible]E 03 | 8.994E 02 |
| 1.280E 02 | 8.730E 02 | 1.164E 03 | 9.616E 02 |
| 1.370E 02 | 8.829E 02 | 1.250E 03 | 1.110E 03 |
| 1.510E 02 | 8.417E 02 | 1.385E 03 | 1.362E 03 |
| 1.670E 02 | 7.836E 02 | 1.540E 03 | 1.684E 03 |
| 1.830E 02 | 7.439E 02 | 1.[illegible]95E 03 | 2.041E 03 |
| 2.000E 02 | 7.161E 02 | 1.[illegible]31E 03 | 2.381E 03 |
| 2.190E 02 | 6.983E 02 | 1.[illegible]81E 03 | 2.787E 03 |
| 2.450E 02 | 6.844E 02 | 2.183E 03 | 3.386E 03 |
| 2.700E 02 | 7.538E 02 | 2.37[illegible]E 03 | 4.009E 03 |

NOT REPRODUCIBLE

## Table IVm

```
                         SOLUTION NUMBER  107

                         NOZZLE NUMBER       1

PRESS (PSI)          L/D           U (CM/SEC)          h

 4.500E 00         7.016E 01       1.611E 02       4.515E 01
 6.700E 00         1.869E 02       2.688E 02       1.257E 02
 8.700E 00         1.736E 02       3.442E 02       2.060E 02
 1.050E 01         1.673E 02       4.058E 02       2.864E 02
 1.250E 01         1.678E 02       4.729E 02       3.889E 02
 1.480E 01         1.686E 02       5.484E 02       5.231E 02
 3.000E 00         4.046E 01       8.053E 01       1.128E 01
 4.000E 00         6.434E 01       1.372E 02       3.279E 01
 5.000E 00         9.381E 01       2.152E 02       8.056E 01
 7.500E 00         1.881E 02       2.938E 02       1.501E 02
 8.600E 00         1.727E 02       3.399E 02       2.009E 02
 6.500E 00         1.855E 02       2.722E 02       1.107E 02
 8.000E 00         1.830E 02       3.147E 02       1.722E 02
 9.500E 00         1.715E 02       3.717E 02       2.403E 02
 1.010E 01         1.684E 02       3.922E 02       2.676E 02
 1.100E 01         1.668E 02       4.227E 02       3.108E 02
 1.150E 01         1.672E 02       4.395E 02       3.360E 02
```

## Table IVn

```
                         SOLUTION NUMBER  110

                         ORIFICE NUMBER  3a

PRESS (PSI)          L/D           U (CM/SEC)          h

 7.500E 00         9.469E 02       6.084E 02       5.288E 02
 5.500E 00         7.631E 02       5.050E 02       3.644E 02
 6.600E 00         8.083E 02       5.645E 02       4.553E 02
 8.400E 00         9.029E 02       6.484E 02       6.007E 02
 1.000E 01         9.917E 02       7.113E 02       7.228E 02
 1.080E 01         9.938E 02       7.394E 02       7.811E 02
 1.250E 01         1.113E 03       7.935E 02       8.995E 02
 1.750E 01         1.259E 03       9.328E 02       1.243E 03
```

## Table IVo

### SOLUTION NUMBER 111

### NOZZLE NUMBER 2

| PRESS (PSI) | L/C | U (CM/SEC) | W |
|---|---|---|---|
| 2.860E 01 | 9.328E 01 | 2.746E 02 | 6.174E 01 |
| 3.500E 01 | 1.717E 02 | 3.846E 02 | 1.052E 02 |
| 4.100E 01 | 2.064E 02 | 4.654E 02 | 1.541E 02 |
| 4.500E 01 | 2.302E 02 | 5.208E 02 | 1.930E 02 |
| 5.000E 01 | 1.905E 02 | 5.914E 02 | 2.488E 02 |
| 5.500E 01 | 2.063E 02 | 6.587E 02 | 3.087E 02 |
| 6.000E 01 | 2.321E 02 | 7.232E 02 | 3.721E 02 |
| 6.500E 01 | 2.500E 02 | 7.881E 02 | 4.419E 02 |
| 7.500E 01 | 2.698E 02 | 9.189E 02 | 6.068E 02 |
| 4.000E 01 | 1.766E 02 | 4.516E 02 | 1.452E 02 |
| 4.500E 01 | 2.083E 02 | 5.208E 02 | 1.930E 02 |
| 5.000E 01 | 2.341E 02 | 5.914E 02 | 2.488E 02 |
| 5.500E 01 | 2.520E 02 | 6.587E 02 | 3.087E 02 |
| 6.000E 01 | 2.649E 02 | 7.232E 02 | 3.721E 02 |
| 6.500E 01 | 2.728E 02 | 7.881E 02 | 4.419E 02 |
| 7.000E 01 | 2.162E 02 | 8.533E 02 | 5.181E 02 |
| 7.100E 01 | 2.738E 02 | 8.664E 02 | 5.341E 02 |
| 7.600E 01 | 2.777E 02 | 9.321E 02 | 6.181E 02 |
| 8.500E 01 | 2.817E 02 | 1.046E 03 | 7.810E 02 |
| 9.600E 01 | 2.936E 02 | 1.174E 03 | 9.806E 02 |
| 1.200E 02 | 3.095E 02 | 1.446E 03 | 1.488E 03 |
| 1.550E 02 | 3.253E 02 | 1.816E 03 | 2.348E 03 |
| 1.700E 02 | 3.472E 02 | 1.957E 03 | 2.725E 03 |
| 1.970E 02 | 3.729E 02 | 2.204E 03 | 3.455E 03 |
| 2.250E 02 | 3.987E 02 | 2.453E 03 | 4.281E 03 |
| 2.550E 02 | 4.305E 02 | 2.713E 03 | 5.238E 03 |
| 3.350E 02 | 4.840E 02 | 3.296E 03 | 7.730E 03 |
| 3.850E 02 | 5.098E 02 | 3.633E 03 | 9.393E 03 |
| 4.400E 02 | 5.257E 02 | 3.990E 03 | 1.132E 04 |
| 5.000E 02 | 5.416E 02 | 4.363E 03 | 1.355E 04 |

Table IVp

SOLUTION NUMBER 111

NOZZLE NUMBER 1

| PRESS (PSI) | L/D | U (CM/SEC) | h |
|---|---|---|---|
| 1.050E 01 | 7.418E 01 | 1.620E 02 | 4.629E 01 |
| 1.260E 01 | 1.144E 02 | 2.154E 02 | 8.188E 01 |
| 1.500E 01 | 1.383E 02 | 2.743E 02 | 1.328E 02 |
| 1.780E 01 | 1.729E 02 | 3.472E 02 | 2.127E 02 |
| 2.060E 01 | 1.983E 02 | 4.129E 02 | 3.008E 02 |
| 2.270E 01 | 2.141E 02 | 4.633E 02 | 3.787E 02 |
| 2.450E 01 | 2.220E 02 | 5.072E 02 | 4.538E 02 |
| 2.670E 01 | 2.178E 02 | 5.674E 02 | 5.680E 02 |
| 2.850E 01 | 2.074E 02 | 6.004E 02 | 6.359E 02 |
| 3.000E 01 | 1.889E 02 | 6.319E 02 | 7.043E 02 |
| 3.500E 01 | 1.849E 02 | 7.368E 02 | 9.577E 02 |
| 4.000E 01 | 1.856E 02 | 8.416E 02 | 1.250E 03 |
| 4.500E 01 | 1.892E 02 | 9.447E 02 | 1.574E 03 |
| 5.000E 01 | 1.984E 02 | 1.031E 03 | 1.876E 03 |
| 5.500E 01 | 2.040E 02 | 1.116E 03 | 2.199E 03 |
| 5.700E 01 | 2.112E 02 | 1.150E 03 | 2.333E 03 |
| 6.500E 01 | 2.368E 02 | 1.283E 03 | 2.904E 03 |
| 7.500E 01 | 2.624E 02 | 1.445E 03 | 3.689E 03 |
| 8.500E 01 | 2.824E 02 | 1.595E 03 | 4.486E 03 |
| 9.500E 01 | 3.000E 02 | 1.725E 03 | 5.250E 03 |
| 1.190E 02 | 3.304E 02 | 2.023E 03 | 7.220E 03 |
| 1.450E 02 | 3.664E 02 | 2.327E 03 | 9.549E 03 |
| 1.700E 02 | 3.864E 02 | 2.596E 03 | 1.189E 04 |
| 1.950E 02 | 4.064E 02 | 2.828E 03 | 1.411E 04 |
| 2.370E 02 | 4.240E 02 | 3.193E 03 | 1.799E 04 |
| 2.750E 02 | 4.384E 02 | 3.503E 03 | 2.164E 04 |
| 3.180E 02 | 4.680E 02 | 3.834E 03 | 2.594E 04 |
| 3.630E 02 | 5.040E 02 | 4.296E 03 | 3.255E 04 |
| 5.100E 02 | 5.560E 02 | 5.058E 03 | 4.513E 04 |

## Table IVq

SOLUTION NUMBER 111

ORIFICE NUMBER 28

| PRESS (PSI) | L/C | U (CM/SEC) | W |
|---|---|---|---|
| 7.500E 00 | 2.837E 02 | 7.217E 02 | 4.787E 02 |
| 9.500E 00 | 3.163E 02 | 7.775E 02 | 5.555E 02 |
| 1.010E 01 | 3.442E 02 | 7.941E 02 | 5.795E 02 |
| 1.260E 01 | 3.660E 02 | 8.623E 02 | 6.833E 02 |
| 1.540E 01 | 3.916E 02 | 9.370E 02 | 8.095E 02 |
| 2.000E 01 | 4.639E 02 | 1.056E 03 | 1.025E 03 |
| 2.480E 01 | 5.136E 02 | 1.174E 03 | 1.271E 03 |
| 2.950E 01 | 5.437E 02 | 1.289E 03 | 1.527E 03 |
| 3.700E 01 | 6.235E 02 | 1.460E 03 | 1.960E 03 |
| 4.500E 01 | 7.079E 02 | 1.631E 03 | 2.446E 03 |
| 6.000E 01 | 8.283E 02 | 1.922E 03 | 3.396E 03 |
| 7.600E 01 | 8.690E 02 | 2.193E 03 | 4.421E 03 |
| 9.000E 01 | 8.795E 02 | 2.400E 03 | 5.295E 03 |
| 1.070E 02 | 9.488E 02 | 2.620E 03 | 6.306E 03 |
| 1.340E 02 | 9.789E 02 | 2.907E 03 | 7.766E 03 |
| 1.540E 02 | 9.925E 02 | 3.084E 03 | 8.740E 03 |
| 1.720E 02 | 9.955E 02 | 3.225E 03 | 9.555E 03 |
| 1.850E 02 | 1.023E 03 | 3.321E 03 | 1.013E 04 |
| 1.960E 02 | 1.030E 03 | 3.399E 03 | 1.062E 04 |
| 2.130E 02 | 1.018E 03 | 3.521E 03 | 1.139E 04 |
| 2.340E 02 | 9.880E 02 | 3.676E 03 | 1.243E 04 |
| 2.650E 02 | 9.458E 02 | 3.946E 03 | 1.431E 04 |
| 3.000E 02 | 9.142E 02 | 4.338E 03 | 1.730E 04 |
| 3.450E 02 | 8.434E 02 | 5.060E 03 | 2.352E 04 |

## Table IVr

SOLUTION NUMBER 111

ORIFICE NUMBER 3a

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 6.000E 00 | 3.053E 02 | 7.327E 02 | 7.635E 02 |
| 8.000E 00 | 3.491E 02 | 7.642E 02 | 8.317E 02 |
| 9.000E 00 | 3.841E 02 | 8.004E 02 | 9.125E 02 |
| 1.240E 01 | 4.298E 02 | 8.632E 02 | 1.061E 03 |
| 1.470E 01 | 4.818E 02 | 9.140E 02 | 1.190E 03 |
| 1.730E 01 | 5.124E 02 | 9.707E 02 | 1.342E 03 |
| 1.930E 01 | 4.987E 02 | 1.014E 03 | 1.464E 03 |
| 2.080E 01 | 5.162E 02 | 1.046E 03 | 1.557E 03 |
| 2.200E 01 | 5.318E 02 | 1.071E 03 | 1.634E 03 |
| 2.520E 01 | 5.531E 02 | 1.138E 03 | 1.844E 03 |
| 2.950E 01 | 5.891E 02 | 1.226E 03 | 2.141E 03 |
| 3.200E 01 | 6.114E 02 | 1.276E 03 | 2.320E 03 |
| 4.100E 01 | 6.619E 02 | 1.452E 03 | 3.001E 03 |
| 4.600E 01 | 6.843E 02 | 1.545E 03 | 3.400E 03 |
| 5.700E 01 | 7.202E 02 | 1.742E 03 | 4.320E 03 |
| 6.000E 01 | 7.464E 02 | 1.793E 03 | 4.579E 03 |
| 7.000E 01 | 7.814E 02 | 1.958E 03 | 5.462E 03 |
| 7.500E 01 | 8.018E 02 | 2.037E 03 | 5.911E 03 |
| 8.600E 01 | 8.348E 02 | 2.203E 03 | 6.912E 03 |
| 9.400E 01 | 8.202E 02 | 2.317E 03 | 7.644E 03 |
| 1.110E 02 | 8.533E 02 | 2.541E 03 | 9.193E 03 |
| 1.400E 02 | 8.776E 02 | 2.872E 03 | 1.175E 04 |
| 1.350E 02 | 8.824E 02 | 2.815E 03 | 1.132E 04 |
| 1.700E 02 | 8.319E 02 | 3.158E 03 | 1.420E 04 |
| 2.000E 02 | 8.047E 02 | 3.397E 03 | 1.643E 04 |
| 2.280E 02 | 7.901E 02 | 3.588E 03 | 1.834E 04 |
| 2.600E 02 | 7.872E 02 | 3.781E 03 | 2.036E 04 |
| 2.400E 02 | 7.862E 02 | 3.667E 03 | 1.911E 04 |
| 3.000E 02 | 7.541E 02 | 4.006E 03 | 2.285E 04 |
| 3.500E 02 | 7.415E 02 | 4.299E 03 | 2.632E 04 |
| 4.000E 02 | 7.386E 02 | 4.657E 03 | 3.085E 04 |
| 1.200E 02 | 8.951E 02 | 2.650E 03 | 1.000E 04 |
| 1.310E 02 | 9.048E 02 | 2.776E 03 | 1.097E 04 |

## Table IVs

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                       SOLUTION NUMBER  112

                       NOZZLE NUMBER      1

PRESS (PSI)           L/L          U (CM/SEC)            W

 9.000E 00        8.079E 01        1.566E 02        4.089E 01
 1.140E 01        1.158E 02        2.257E 02        8.492E 01
 1.430E 01        1.489E 02        3.107E 02        1.609E 02
 1.750E 01        1.830E 02        4.022E 02        2.697E 02
 1.950E 01        2.077E 02        4.583E 02        3.500E 02
 2.260E 01        2.139E 02        5.475E 02        4.996E 02
 2.470E 01        2.002E 02        6.020E 02        6.039E 02
 2.340E 01        2.090E 02        5.703E 02        5.421E 02
 2.200E 01        2.179E 02        5.300E 02        4.682E 02
 2.130E 01        2.164E 02        5.098E 02        4.331E 02
 2.670E 01        1.849E 02        6.506E 02        7.055E 02
 2.940E 01        1.745E 02        7.163E 02        8.551E 02
 3.200E 01        1.648E 02        7.795E 02        1.013E 03
 3.500E 01        1.688E 02        8.525E 02        1.211E 03
 4.100E 01        1.812E 02        9.867E 02        1.623E 03
 5.000E 01        2.168E 02        1.161E 03        2.246E 03
 5.500E 01        2.312E 02        1.255E 03        2.626E 03
 6.000E 01        2.440E 02        1.348E 03        3.028E 03
 6.500E 01        2.680E 02        1.439E 03        3.452E 03
 7.500E 01        2.808E 02        1.606E 03        4.297E 03
 8.600E 01        3.040E 02        1.764E 03        5.187E 03
 9.300E 01        3.152E 02        1.867E 03        5.776E 03
 1.060E 02        3.304E 02        2.037E 03        6.915E 03
 1.150E 02        3.344E 02        2.154E 03        7.735E 03
 1.300E 02        3.424E 02        2.344E 03        9.155E 03
 1.500E 02        3.592E 02        2.581E 03        1.110E 04
 1.640E 02        3.648E 02        2.723E 03        1.236E 04
 1.740E 02        3.920E 02        2.822E 03        1.328E 04
 2.140E 02        3.920E 02        3.197E 03        1.704E 04
 2.800E 02        4.192E 02        3.760E 03        2.357E 04
 3.290E 02        4.276E 02        4.193E 03        2.930E 04
 3.720E 02        4.616E 02        4.440E 03        3.286E 04
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## Table IVt

SOLUTION NUMBER 112

NOZZLE NUMBER 2

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 3.100E 01 | 1.329E 02 | 4.121E 02 | 1.142E 02 |
| 3.500E 01 | 1.607E 02 | 4.789E 02 | 1.542E 02 |
| 4.000E 01 | 1.845E 02 | 5.650E 02 | 2.146E 02 |
| 4.500E 01 | 2.063E 02 | 6.494E 02 | 2.834E 02 |
| 5.000E 01 | 2.267E 02 | 7.270E 02 | 3.553E 02 |
| 5.500E 01 | 2.371E 02 | 8.053E 02 | 4.359E 02 |
| 6.000E 01 | 2.400E 02 | 8.840E 02 | 5.253E 02 |
| 6.500E 01 | 2.381E 02 | 9.633E 02 | 6.237E 02 |
| 7.000E 01 | 2.381E 02 | 1.040E 03 | 7.273E 02 |
| 7.500E 01 | 2.420E 02 | 1.107E 03 | 8.244E 02 |
| 8.000E 01 | 2.450E 02 | 1.174E 03 | 9.268E 02 |
| 9.000E 01 | 2.519E 02 | 1.307E 03 | 1.148E 03 |
| 1.030E 02 | 2.609E 02 | 1.477E 03 | 1.466E 03 |
| 1.480E 02 | 2.847E 02 | 1.991E 03 | 2.665E 03 |
| 1.700E 02 | 2.995E 02 | 2.215E 03 | 3.296E 03 |
| 1.800E 02 | 2.976E 02 | 2.314E 03 | 3.598E 03 |
| 2.000E 02 | 3.392E 02 | 2.508E 03 | 4.228E 03 |
| 2.340E 02 | 3.829E 02 | 2.823E 03 | 5.357E 03 |
| 2.550E 02 | 4.047E 02 | 2.988E 03 | 6.002E 03 |
| 3.100E 02 | 4.463E 02 | 3.400E 03 | 7.771E 03 |
| 3.660E 02 | 4.662E 02 | 3.795E 03 | 9.680E 03 |
| 4.150E 02 | 4.801E 02 | 4.124E 03 | 1.143E 04 |
| 4.470E 02 | 4.880E 02 | 4.331E 03 | 1.261E 04 |
| 4.920E 02 | 4.979E 02 | 4.613E 03 | 1.430E 04 |

## Table IVu

SOLUTION NUMBER 112

ORIFICE NUMBER 2a

| PRESS (PSI) | L/D | U (CM/SEC) | h |
|---|---|---|---|
| 6.000E 00 | 2.139E 02 | 6.605E 02 | 3.862E 02 |
| 7.600E 00 | 2.516E 02 | 7.078E 02 | 4.436E 02 |
| 1.100E 01 | 2.982E 02 | 8.067E 02 | 5.761E 02 |
| 1.400E 01 | 3.404E 02 | 8.918E 02 | 7.041E 02 |
| 1.800E 01 | 3.871E 02 | 1.002E 03 | 8.894E 02 |
| 2.370E 01 | 4.443E 02 | 1.154E 03 | 1.179E 03 |
| 2.840E 01 | 4.835E 02 | 1.274E 03 | 1.437E 03 |
| 3.500E 01 | 5.226E 02 | 1.436E 03 | 1.825E 03 |
| 4.500E 01 | 5.896E 02 | 1.664E 03 | 2.453E 03 |
| 6.000E 01 | 6.627E 02 | 1.974E 03 | 3.451E 03 |
| 7.500E 01 | 7.319E 02 | 2.247E 03 | 4.470E 03 |
| 9.600E 01 | 7.831E 02 | 2.574E 03 | 5.865E 03 |
| 1.400E 02 | 8.539E 02 | 3.090E 03 | 8.455E 03 |
| 1.610E 02 | 8.765E 02 | 3.277E 03 | 9.509E 03 |
| 1.900E 02 | 9.059E 02 | 3.496E 03 | 1.082E 04 |
| 2.130E 02 | 9.127E 02 | 3.653E 03 | 1.182E 04 |
| 2.690E 02 | 8.870E 02 | 4.058E 03 | 1.458E 04 |
| 2.950E 02 | 8.630E 02 | 4.296E 03 | 1.634E 04 |
| 3.400E 02 | 8.133E 02 | 4.855E 03 | 2.087E 04 |
| 2.340E 02 | 9.172E 02 | 3.796E 03 | 1.275E 04 |
| 2.550E 02 | 8.976E 02 | 3.947E 03 | 1.379E 04 |
| 2.150E 02 | 9.217E 02 | 3.667E 03 | 1.190E 04 |

## Table IVv

SOLUTION NUMBER 112

ORIFICE NUMBER 3a

| PRESS (PSI) | L/D | U (CM/SEC) | h |
|---|---|---|---|
| 7.000E 00 | 2.382E 02 | 6.958E 02 | 6.642E 02 |
| 8.500E 00 | 2.635E 02 | 7.182E 02 | 7.477E 02 |
| 2.400E 00 | 1.205E 02 | 5.625E 02 | 4.341E 02 |
| 3.800E 00 | 1.701E 02 | 6.036E 02 | 4.998E 02 |
| 5.500E 00 | 2.081E 02 | 6.526E 02 | 5.847E 02 |
| 1.040E 01 | 2.887E 02 | 7.912E 02 | 8.590E 02 |
| 1.350E 01 | 3.159E 02 | 8.761E 02 | 1.053E 03 |
| 1.720E 01 | 3.480E 02 | 9.746E 02 | 1.303E 03 |
| 2.180E 01 | 3.854E 02 | 1.093E 03 | 1.639E 03 |
| 2.750E 01 | 4.223E 02 | 1.234E 03 | 2.088E 03 |
| 3.000E 01 | 4.588E 02 | 1.293E 03 | 2.295E 03 |
| 3.500E 01 | 4.845E 02 | 1.409E 03 | 2.724E 03 |
| 4.000E 01 | 5.083E 02 | 1.520E 03 | 3.169E 03 |
| 4.500E 01 | 5.238E 02 | 1.626E 03 | 3.627E 03 |
| 5.000E 01 | 5.491E 02 | 1.727E 03 | 4.094E 03 |
| 5.500E 01 | 5.637E 02 | 1.825E 03 | 4.567E 03 |
| 6.700E 01 | 6.064E 02 | 2.041E 03 | 5.714E 03 |
| 7.500E 01 | 6.307E 02 | 2.172E 03 | 6.473E 03 |
| 8.600E 01 | 6.628E 02 | 2.338E 03 | 7.497E 03 |
| 9.600E 01 | 6.842E 02 | 2.474E 03 | 8.396E 03 |
| 1.250E 02 | 7.444E 02 | 2.802E 03 | 1.077E 04 |
| 1.570E 02 | 7.454E 02 | 3.076E 03 | 1.298E 04 |
| 1.810E 02 | 7.308E 02 | 3.242E 03 | 1.442E 04 |
| 2.050E 02 | 7.162E 02 | 3.391E 03 | 1.578E 04 |
| 1.400E 02 | 7.911E 02 | 2.940E 03 | 1.186E 04 |
| 1.560E 02 | 7.794E 02 | 3.069E 03 | 1.292E 04 |
| 1.900E 02 | 7.454E 02 | 3.299E 03 | 1.493E 04 |
| 2.300E 02 | 7.434E 02 | 3.545E 03 | 1.724E 04 |
| 2.580E 02 | 7.347E 02 | 3.737E 03 | 1.916E 04 |
| 3.220E 02 | 7.230E 02 | 4.384E 03 | 2.636E 04 |

NOT REPRODUCIBLE

## Table IVw

SOLUTION NUMBER 115

NOZZLE NUMBER 1

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 1.900E 01 | 1.770E 02 | 2.140E 02 | 7.738E 01 |
| 2.200E 01 | 2.236E 02 | 2.773E 02 | 1.299E 02 |
| 2.320E 01 | 2.414E 02 | 3.047E 02 | 1.568E 02 |
| 2.520E 01 | 2.678E 02 | 3.513E 02 | 2.084E 02 |
| 2.700E 01 | 2.930E 02 | 3.893E 02 | 2.561E 02 |
| 2.950E 01 | 3.327E 02 | 4.443E 02 | 3.335E 02 |
| 3.500E 01 | 4.631E 02 | 5.722E 02 | 5.531E 02 |
| 4.400E 01 | 5.324E 02 | 7.529E 02 | 9.575E 02 |
| 5.300E 01 | 4.731E 02 | 9.399E 02 | 1.492E 03 |
| 5.500E 01 | 4.643E 02 | 9.733E 02 | 1.600E 03 |
| 6.500E 01 | 4.281E 02 | 1.139E 03 | 2.192E 03 |
| 7.600E 01 | 4.121E 02 | 1.320E 03 | 2.942E 03 |
| 8.500E 01 | 4.064E 02 | 1.466E 03 | 3.632E 03 |
| 1.000E 02 | 4.120E 02 | 1.674E 03 | 4.732E 03 |
| 1.300E 02 | 4.424E 02 | 2.039E 03 | 7.021E 03 |
| 1.570E 02 | 4.760E 02 | 2.350E 03 | 9.325E 03 |
| 1.830E 02 | 5.037E 02 | 2.621E 03 | 1.161E 04 |
| 2.250E 02 | 5.472E 02 | 2.987E 03 | 1.507E 04 |
| 3.000E 02 | 5.648E 02 | 3.582E 03 | 2.167E 04 |
| 4.000E 02 | 6.144E 02 | 4.284E 03 | 3.100E 04 |
| 4.500E 01 | 5.226E 02 | 7.735E 02 | 1.011E 03 |
| 4.800E 01 | 5.199E 02 | 8.357E 02 | 1.180E 03 |
| 4.300E 01 | 5.244E 02 | 7.324E 02 | 9.061E 02 |
| 4.000E 01 | 5.112E 02 | 6.716E 02 | 7.618E 02 |
| 4.100E 01 | 5.159E 02 | 6.919E 02 | 8.083E 02 |

NOT REPRODUCIBLE

## Table IVx

SOLUTION NUMBER 115

ORIFICE NUMBER 2a

| PRESS (PSI) | L/D | U (CM/SEC) | h |
|---|---|---|---|
| 8.000E 00 | 4.809E 02 | 6.463E 02 | 3.748E 02 |
| 4.400E 01 | 2.952E 02 | 1.642E 03 | 2.419E 03 |
| 6.200E 00 | 4.055E 02 | 5.852E 02 | 3.073E 02 |
| 1.180E 01 | 6.308E 02 | 7.714E 02 | 5.339E 02 |
| 1.510E 01 | 7.339E 02 | 8.759E 02 | 6.883E 02 |
| 2.040E 01 | 8.980E 02 | 1.036E 03 | 9.628E 02 |
| 2.640E 01 | 1.030E 03 | 1.206E 03 | 1.305E 03 |
| 2.900E 01 | 1.068E 03 | 1.276E 03 | 1.461E 03 |
| 3.600E 01 | 1.265E 03 | 1.455E 03 | 1.899E 03 |
| 4.500E 01 | 1.377E 03 | 1.664E 03 | 2.485E 03 |
| 5.500E 01 | 1.460E 03 | 1.872E 03 | 3.149E 03 |
| 5.800E 01 | 1.464E 03 | 1.930E 03 | 3.342E 03 |
| 6.600E 01 | 1.490E 03 | 2.074E 03 | 3.860E 03 |
| 7.000E 01 | 1.524E 03 | 2.141E 03 | 4.114E 03 |
| 8.100E 01 | 1.601E 03 | 2.311E 03 | 4.791E 03 |
| 8.900E 01 | 1.619E 03 | 2.422E 03 | 5.262E 03 |
| 9.500E 01 | 1.670E 03 | 2.499E 03 | 5.604E 03 |
| 1.230E 02 | 1.747E 03 | 2.912E 03 | 7.094E 03 |
| 1.460E 02 | 1.759E 03 | 3.041E 03 | 8.296E 03 |
| 1.650E 02 | 1.700E 03 | 3.237E 03 | 9.400E 03 |
| 1.850E 02 | 1.596E 03 | 3.472E 03 | 1.082E 04 |

## Table IVy

SOLUTION NUMBER 115

ORIFICE NUMBER 3a

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 4.800E 00 | 4.001E 02 | 5.011E 02 | 3.492E 02 |
| 6.100E 00 | 4.625E 02 | 5.477E 02 | 4.171E 02 |
| 7.600E 00 | 5.296E 02 | 6.005E 02 | 5.015E 02 |
| 9.400E 00 | 5.603E 02 | 6.628E 02 | 6.108E 02 |
| 1.260E 01 | 8.607E 02 | 7.702E 02 | 8.249E 02 |
| 7.600E 00 | 6.488E 02 | 6.005E 02 | 5.015E 02 |
| 9.800E 00 | 7.379E 02 | 6.764E 02 | 6.362E 02 |
| 1.460E 01 | 8.632E 02 | 8.354E 02 | 9.704E 02 |
| 1.780E 01 | 9.474E 02 | 9.365E 02 | 1.219E 03 |
| 2.130E 01 | 1.043E 03 | 1.043E 03 | 1.512E 03 |
| 2.020E 01 | 1.020E 03 | 1.010E 03 | 1.418E 03 |
| 2.520E 01 | 1.131E 03 | 1.156E 03 | 1.858E 03 |
| 3.000E 01 | 1.181E 03 | 1.288E 03 | 2.306E 03 |
| 3.300E 01 | 1.222E 03 | 1.366E 03 | 2.596E 03 |
| 3.700E 01 | 1.241E 03 | 1.467E 03 | 2.991E 03 |
| 4.500E 01 | 1.275E 03 | 1.652E 03 | 3.797E 03 |
| 5.000E 01 | 1.338E 03 | 1.759E 03 | 4.303E 03 |
| 4.900E 01 | 1.412E 03 | 1.738E 03 | 4.202E 03 |
| 5.500E 01 | 1.417E 03 | 1.859E 03 | 4.806E 03 |
| 6.100E 01 | 1.409E 03 | 1.971E 03 | 5.400E 03 |
| 7.500E 01 | 1.386E 03 | 2.199E 03 | 6.725E 03 |
| 2.100E 01 | 1.007E 03 | 1.034E 03 | 1.486E 03 |
| 3.000E 01 | 1.173E 03 | 1.288E 03 | 2.306E 03 |
| 3.500E 01 | 1.238E 03 | 1.417E 03 | 2.793E 03 |
| 4.000E 01 | 1.262E 03 | 1.539E 03 | 3.292E 03 |
| 1.550E 02 | 1.294E 03 | 3.041E 03 | 1.286E 04 |
| 1.830E 02 | 1.143E 03 | 3.341E 03 | 1.552E 04 |
| 2.000E 02 | 1.061E 03 | 3.575E 03 | 1.777E 04 |
| 1.350E 02 | 1.393E 03 | 2.856E 03 | 1.136E 04 |
| 1.420E 02 | 1.385E 03 | 2.921E 03 | 1.186E 04 |
| 1.740E 02 | 1.160E 03 | 3.235E 03 | 1.456E 04 |
| 1.910E 02 | 1.119E 03 | 3.445E 03 | 1.650E 04 |
| 1.620E 02 | 1.272E 03 | 3.109E 03 | 1.344E 04 |

## Table IVz

SOLUTION NUMBER 117

NOZZLE NUMBER 1

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 4.400E 01 | 6.263E 02 | 5.735E 02 | 5.409E 02 |
| 5.600E 01 | 7.402E 02 | 7.886E 02 | 1.023E 03 |
| 6.500E 01 | 7.871E 02 | 9.550E 02 | 1.500E 03 |
| 7.000E 01 | 7.578E 02 | 1.032E 03 | 1.751E 03 |
| 7.600E 01 | 7.174E 02 | 1.125E 03 | 2.080E 03 |
| 8.000E 01 | 6.852E 02 | 1.187E 03 | 2.316E 03 |
| 8.500E 01 | 6.531E 02 | 1.264E 03 | 2.629E 03 |
| 9.000E 01 | 6.194E 02 | 1.342E 03 | 2.962E 03 |
| 3.500E 01 | 4.934E 02 | 3.983E 02 | 2.609E 02 |
| 4.000E 01 | 5.740E 02 | 4.933E 02 | 4.003E 02 |
| 4.500E 01 | 6.527E 02 | 5.908E 02 | 5.740E 02 |
| 5.000E 01 | 7.179E 02 | 6.790E 02 | 7.582E 02 |
| 5.600E 01 | 7.442E 02 | 7.886E 02 | 1.023E 03 |
| 6.000E 01 | 7.265E 02 | 8.639E 02 | 1.227E 03 |
| 6.400E 01 | 6.778E 02 | 9.397E 02 | 1.452E 03 |
| 7.000E 01 | 6.310E 02 | 1.032E 03 | 1.751E 03 |
| 7.500E 01 | 6.132E 02 | 1.109E 03 | 2.023E 03 |
| 8.500E 01 | 5.370E 02 | 1.264E 03 | 2.629E 03 |
| 9.000E 01 | 5.249E 02 | 1.342E 03 | 2.962E 03 |
| 9.400E 01 | 5.185E 02 | 1.404E 03 | 3.244E 03 |
| 4.000E 01 | 5.424E 02 | 4.933E 02 | 4.003E 02 |
| 4.500E 01 | 6.101E 02 | 5.908E 02 | 5.740E 02 |
| 5.100E 01 | 6.841E 02 | 6.970E 02 | 7.990E 02 |
| 5.500E 01 | 7.154E 02 | 7.701E 02 | 9.753E 02 |
| 6.000E 01 | 7.225E 02 | 8.639E 02 | 1.227E 03 |
| 6.500E 01 | 6.801E 02 | 9.550E 02 | 1.500E 03 |
| 3.800E 01 | 5.432E 02 | 4.544E 02 | 3.396E 02 |
| 4.500E 01 | 6.544E 02 | 5.908E 02 | 5.740E 02 |
| 5.100E 01 | 7.117E 02 | 6.970E 02 | 7.990E 02 |
| 5.600E 01 | 7.434E 02 | 7.886E 02 | 1.023E 03 |
| 6.000E 01 | 7.225E 02 | 8.639E 02 | 1.227E 03 |
| 6.500E 01 | 6.729E 02 | 9.550E 02 | 1.500E 03 |

## Table IVaa

SOLUTION NUMBER 117

ORIFICE NUMBER 2A

| PRESS (PSI) | L/D | U (CM/SEC) | W |
|---|---|---|---|
| 2.500E 01 | 1.070E 03 | 1.165E 03 | 1.187E 03 |
| 3.100E 01 | 1.137E 03 | 1.302E 03 | 1.482E 03 |
| 3.600E 01 | 1.229E 03 | 1.413E 03 | 1.744E 03 |
| 4.100E 01 | 1.267E 03 | 1.520E 03 | 2.018E 03 |
| 5.000E 01 | 1.386E 03 | 1.704E 03 | 2.538E 03 |
| 6.000E 01 | 1.494E 03 | 1.898E 03 | 3.146E 03 |
| 7.000E 01 | 1.569E 03 | 2.079E 03 | 3.776E 03 |
| 8.100E 01 | 1.603E 03 | 2.265E 03 | 4.484E 03 |
| 9.200E 01 | 1.633E 03 | 2.439E 03 | 5.198E 03 |
| 1.010E 02 | 1.661E 03 | 2.573E 03 | 5.783E 03 |
| 1.250E 02 | 1.712E 03 | 2.894E 03 | 7.319E 03 |
| 1.550E 02 | 1.756E 03 | 3.237E 03 | 9.152E 03 |
| 1.850E 02 | 1.660E 03 | 3.530E 03 | 1.089E 04 |
| 2.100E 02 | 1.569E 03 | 3.750E 03 | 1.228E 04 |
| 2.440E 02 | 1.529E 03 | 4.033E 03 | 1.421E 04 |
| 2.750E 02 | 1.423E 03 | 4.296E 03 | 1.612E 04 |
| 1.400E 02 | 1.833E 03 | 3.073E 03 | 8.249E 03 |
| 1.500E 02 | 1.824E 03 | 3.183E 03 | 8.854E 03 |
| 1.190E 02 | 1.752E 03 | 2.818E 03 | 6.939E 03 |
| 1.330E 02 | 1.914E 03 | 2.991E 03 | 7.818E 03 |
| 1.310E 02 | 1.908E 03 | 2.968E 03 | 7.694E 03 |

## Table IVbb

SOLUTION NUMBER 117

NOZZLE NUMBER 2

| PRESS (PSI) | L/D | U (CM/SEC) | |
|---|---|---|---|
| 4.200E 01 | 1.773E 02 | 2.344E 02 | 3.646E 01 |
| 5.800E 01 | 3.378E 02 | 4.020E 02 | 1.072E 02 |
| 6.600E 01 | 4.091E 02 | 4.880E 02 | 1.579E 02 |
| 7.300E 01 | 4.566E 02 | 5.676E 02 | 2.137E 02 |
| 9.200E 01 | 5.993E 02 | 7.737E 02 | 3.971E 02 |
| 1.080E 02 | 6.905E 02 | 9.503E 02 | 5.990E 02 |
| 1.310E 02 | 7.936E 02 | 1.182E 03 | 9.273E 02 |
| 1.510E 02 | 8.015E 02 | 1.376E 03 | 1.255E 03 |
| 1.700E 02 | 7.796E 02 | 1.561E 03 | 1.615E 03 |
| 1.950E 02 | 7.598E 02 | 1.785E 03 | 2.113E 03 |
| 2.120E 02 | 7.459E 02 | 1.920E 03 | 2.446E 03 |
| 2.330E 02 | 7.419E 02 | 2.086E 03 | 2.885E 03 |
| 2.550E 02 | 7.439E 02 | 2.257E 03 | 3.378E 03 |
| 2.810E 02 | 7.469E 02 | 2.457E 03 | 4.003E 03 |
| 3.100E 02 | 7.598E 02 | 2.677E 03 | 4.754E 03 |
| 3.510E 02 | 7.796E 02 | 2.951E 03 | 5.775E 03 |
| 3.910E 02 | 7.975E 02 | 3.192E 03 | 6.759E 03 |
| 4.300E 02 | 8.094E 02 | 3.421E 03 | 7.763E 03 |

## Table IVcc

SOLUTION NUMBER 102

NOZZLE NUMBER 2

| PRESS (PSI) | L/D | U (CM/SEC) | w |
|---|---|---|---|
| 4.300E 01 | 3.060E 02 | 3.933E 02 | 1.100E 02 |
| 6.000E 01 | 4.407E 02 | 5.956E 02 | 2.522E 02 |
| 6.700E 01 | 5.240E 02 | 6.735E 02 | 3.225E 02 |
| 8.100E 01 | 6.013E 02 | 8.224E 02 | 4.809E 02 |
| 9.200E 01 | 6.349E 02 | 9.404E 02 | 6.288E 02 |
| 1.220E 02 | 6.646E 02 | 1.224E 03 | 1.065E 03 |
| 1.500E 02 | 6.705E 02 | 1.470E 03 | 1.536E 03 |
| 1.750E 02 | 6.923E 02 | 1.691E 03 | 2.033E 03 |
| 1.250E 02 | 6.646E 02 | 1.251E 03 | 1.112E 03 |
| 1.000E 02 | 6.528E 02 | 1.026E 03 | 7.492E 02 |
| 8.000E 01 | 6.132E 02 | 8.117E 02 | 4.685E 02 |
| 4.800E 01 | 3.854E 02 | 4.510E 02 | 1.447E 02 |
| 2.500E 01 | 1.218E 02 | 1.743E 02 | 2.155E 01 |

## Table IVdd

SOLUTION NUMBER 117

ORIFICE NUMBER 3A

| PRESS (PSI) | L/D | U (CM/SEC) | w |
|---|---|---|---|
| 1.000E 01 | 8.474E 02 | 1.019E 03 | 1.406E 03 |
| 1.500E 01 | 9.864E 02 | 1.130E 03 | 1.728E 03 |
| 2.100E 01 | 1.197E 03 | 1.258E 03 | 2.143E 03 |
| 2.600E 01 | 1.318E 03 | 1.361E 03 | 2.509E 03 |
| 3.000E 01 | 1.351E 03 | 1.442E 03 | 2.815E 03 |
| 3.600E 01 | 1.417E 03 | 1.559E 03 | 3.290E 03 |
| 3.600E 01 | 1.411E 03 | 1.559E 03 | 3.290E 03 |
| 4.200E 01 | 1.481E 03 | 1.671E 03 | 3.782E 03 |
| 1.080E 02 | 1.486E 03 | 2.658E 03 | 9.568E 03 |
| 1.360E 02 | 1.410E 03 | 2.964E 03 | 1.189E 04 |
| 1.600E 02 | 1.359E 03 | 3.186E 03 | 1.374E 04 |
| 2.000E 02 | 1.181E 03 | 3.499E 03 | 1.658E 04 |
| 2.250E 02 | 1.124E 03 | 3.673E 03 | 1.826E 04 |
| 2.500E 02 | 1.088E 03 | 3.840E 03 | 1.996E 04 |
| 2.950E 02 | 1.031E 03 | 4.154E 03 | 2.337E 04 |
| 3.300E 02 | 1.020E 03 | 4.440E 03 | 2.669E 04 |

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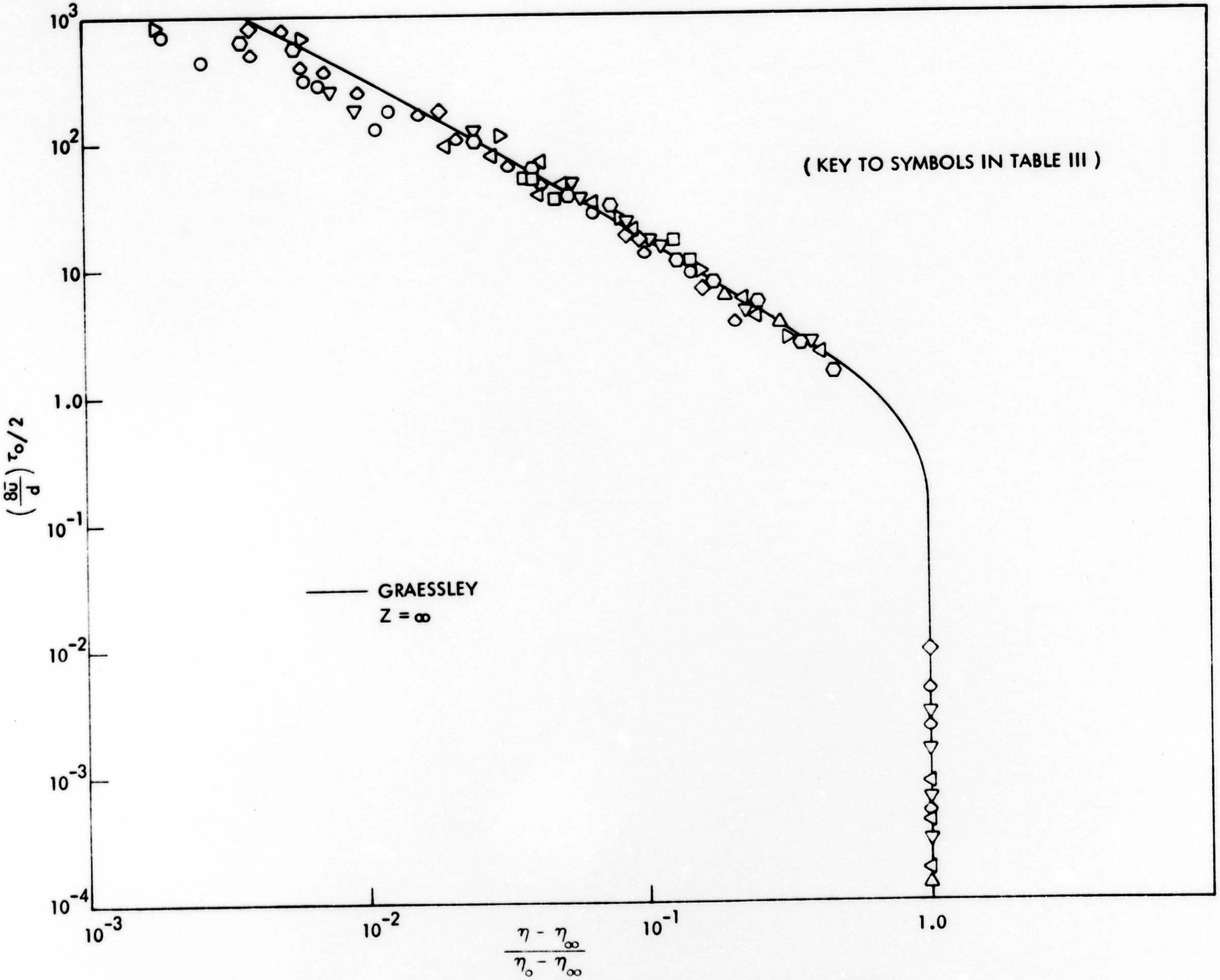

FIG. 1 STRESS-STRAIN RATE FLOW CURVES FOR CMC SOLUTIONS

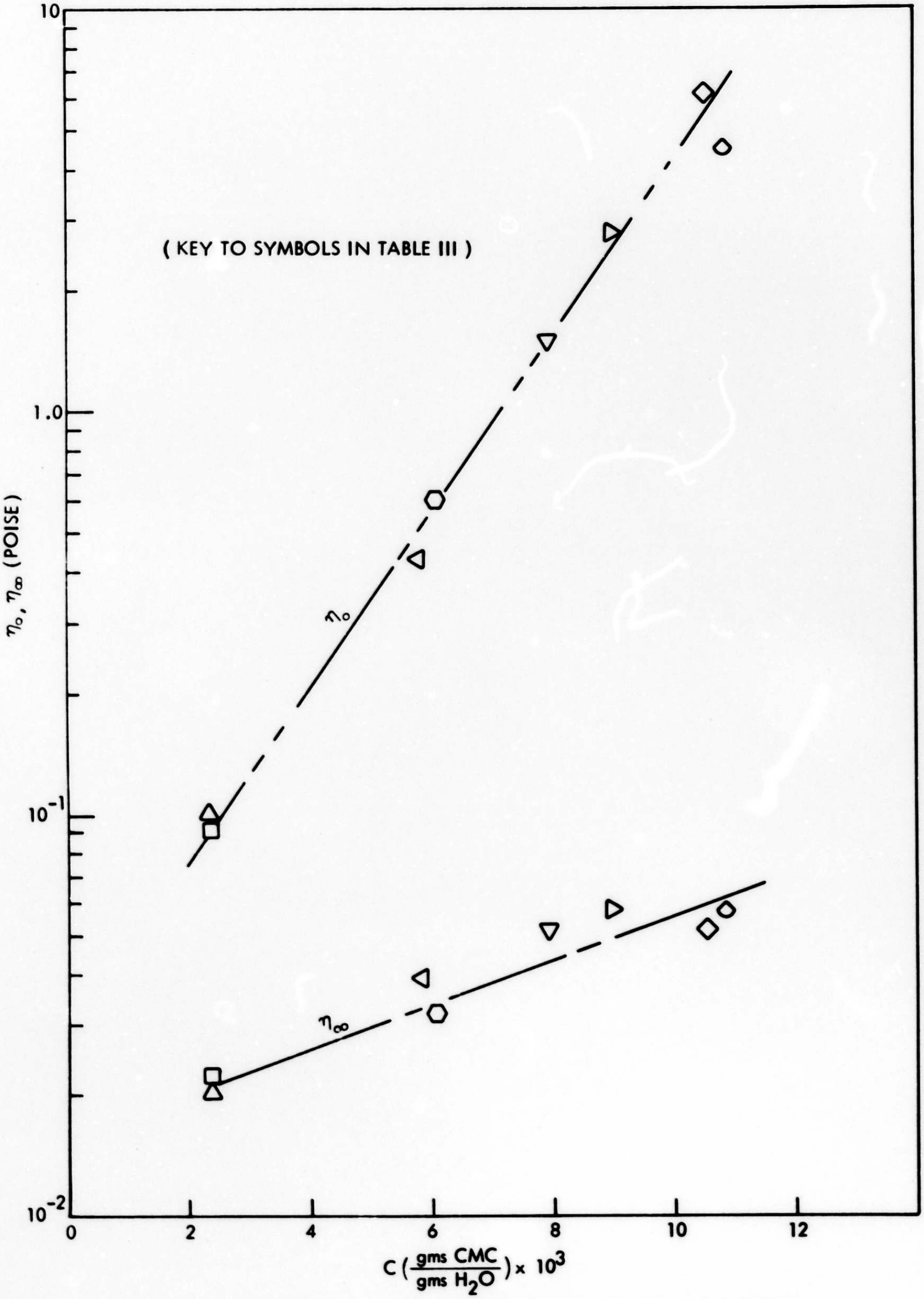

FIG. 2 CHARACTERISTIC VISCOSITY CONSTANTS FOR CMC SOLUTIONS

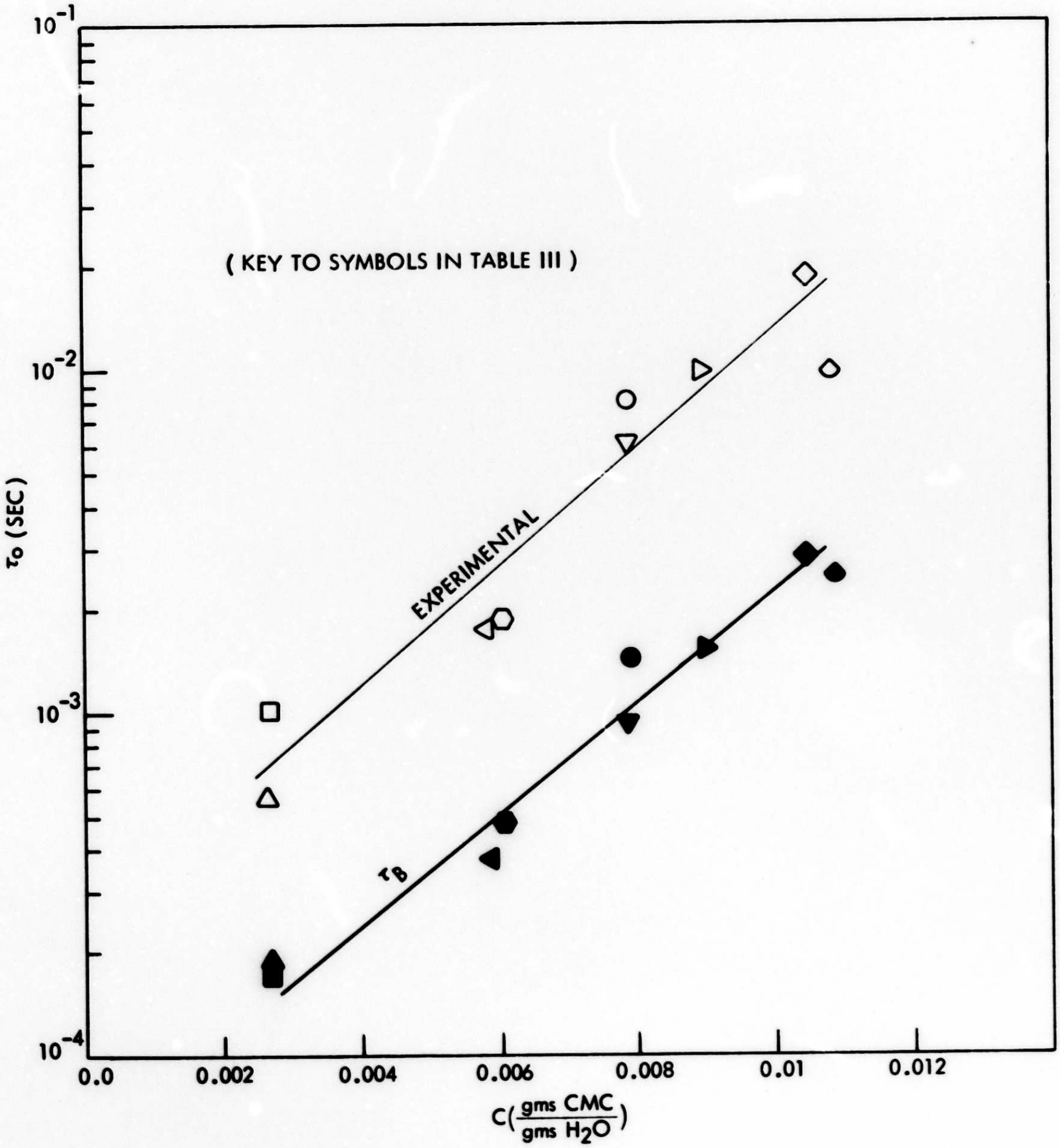

FIG. 3 RELAXATION TIME FOR CMC SOLUTIONS

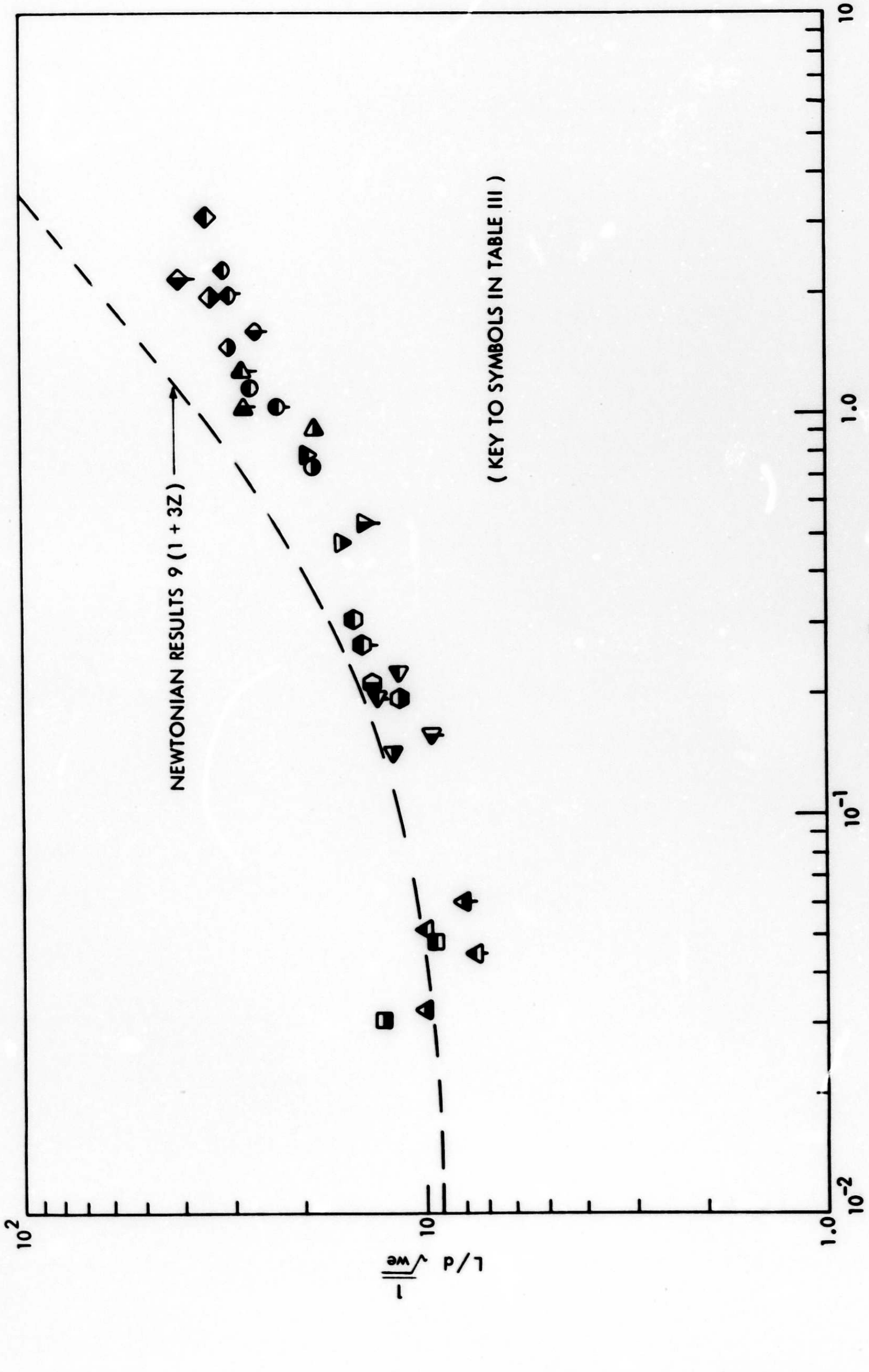

FIG. 4 BREAKUP LENGTH DATA FOR CMC SOLUTIONS

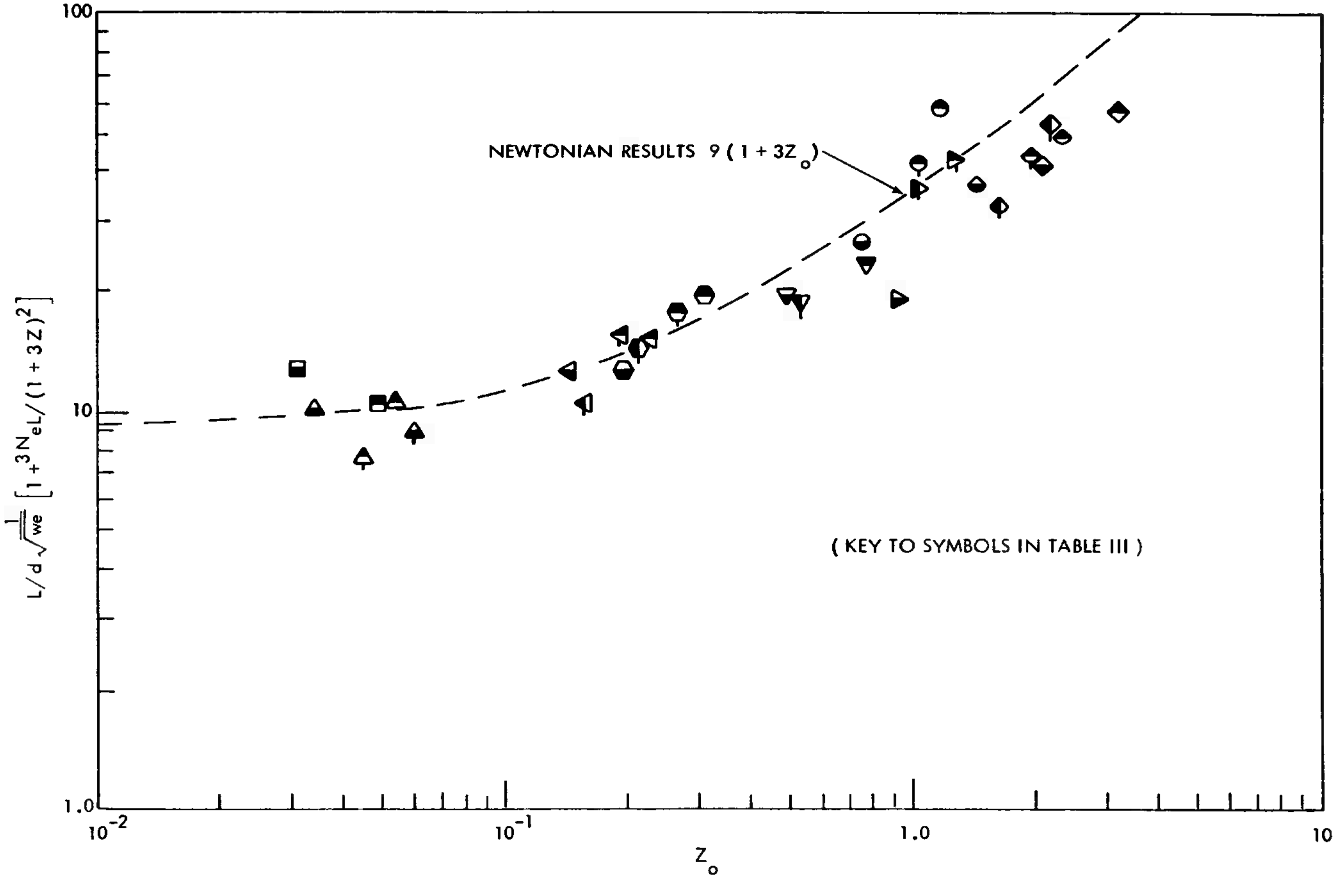

FIG. 5 BREAKUP LENGTH COMPARED TO THEORY OF REF. 2