INVESTIGATION OF THE STRUCTURE OF

INTACT CORE

IN

FULL CONE SPRAYS

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SANDIA LABS

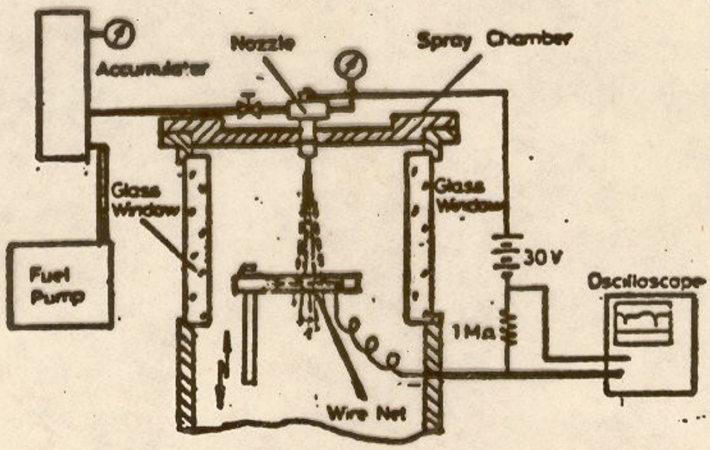


Fig. 8 Experimental apparatus for measuring break-up length

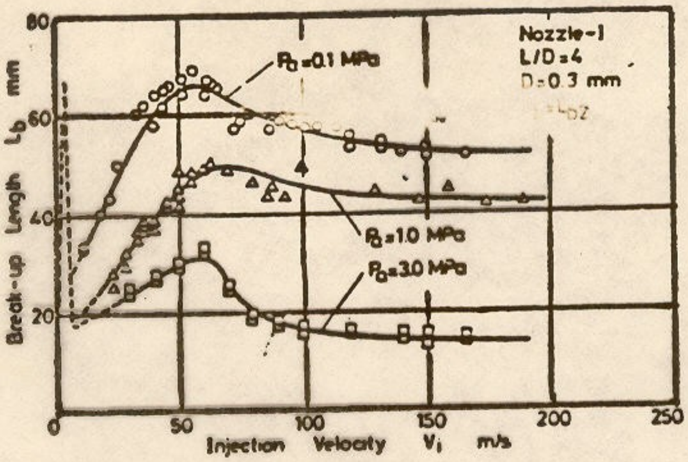
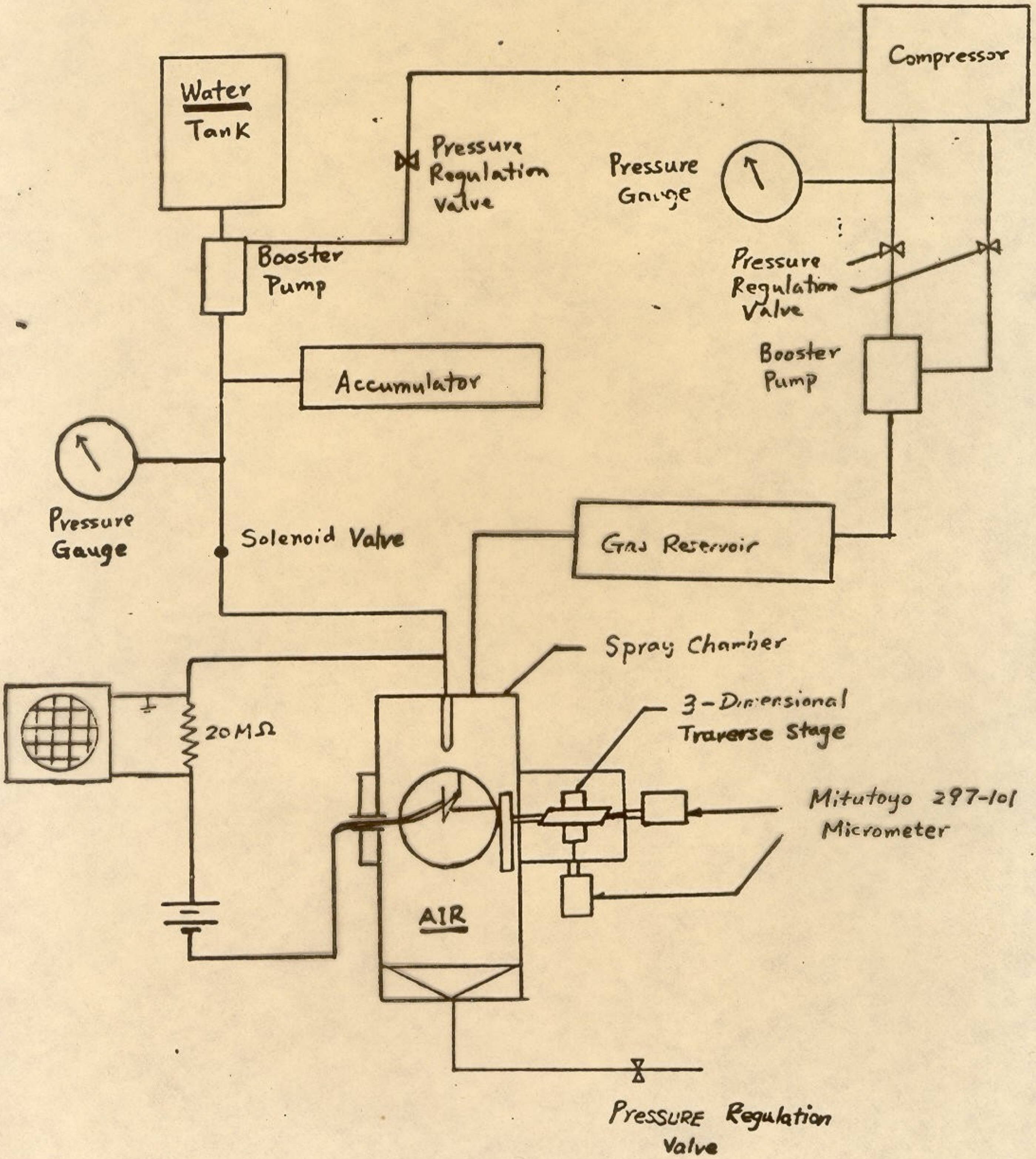


Fig.11 Break-up length

Arai M., Tabata M., Hiroyasu H., and Shimizu M.
"Disintegrating Process and Spray Characterization of Fuel Jet Injected by a Diesel Nozzle"
SAE Tech. Paper No. 840275 (1984)

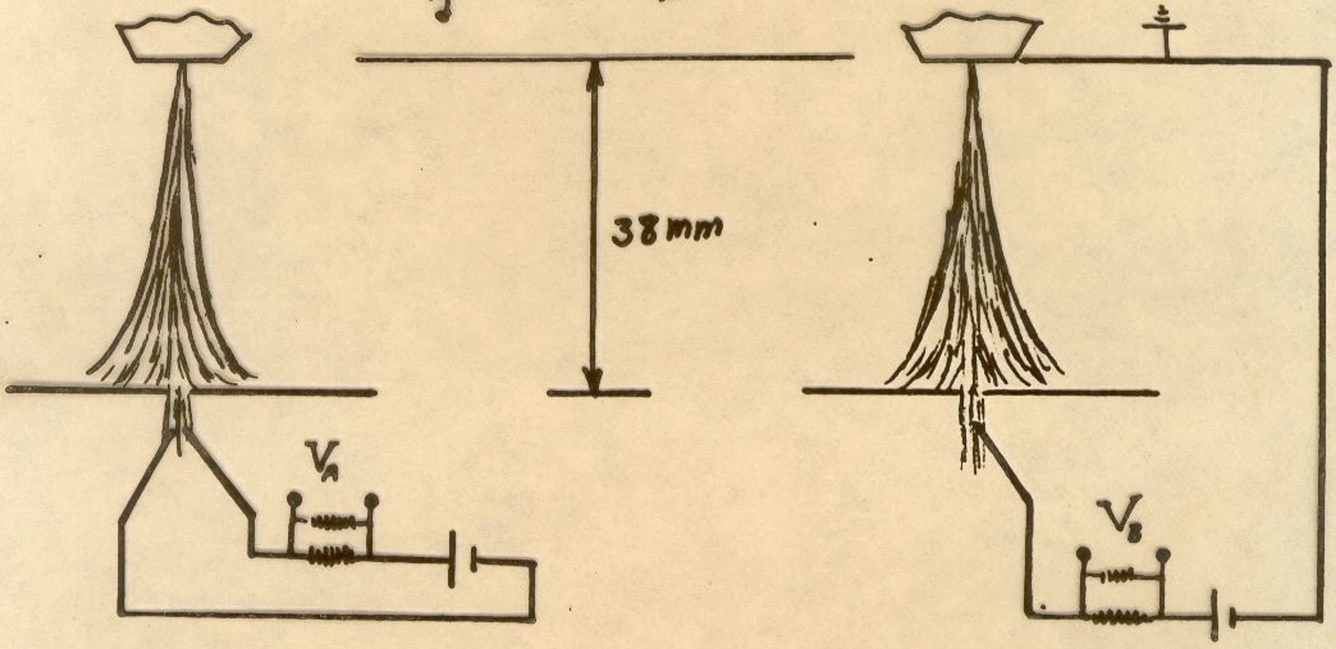
Using water, we decided to check Arai, et al. findings and, most of all, to try and determine the <u>shape</u> of the intact core using a 1 mm diameter bar that can be moved in 3-D instead of the screen that was moved only axially.

Our setup is shown:



Water Tank
Pressure Regulation Valve
Compressor
Pressure Gauge
Booster Pump
Pressure Regulation Valve
Booster Pump
Accumulator
Pressure Gauge
Solenoid Valve
Gas Reservoir
Spray Chamber
20MΩ
3-Dimensional Traverse Stage
Mitutoyo 297-101 Micrometer
AIR
Pressure Regulation Valve

$P_g = 150^{psi}$; $\Delta P_l = 2000^{psi}$



$V_A = 120 - 150^{mV}$
(3,331 – 2,620 MΩ)

V_A (when blocked) = 9-15^{mV}

<u>Gap Size ≃ 250 µm</u>

$V_B = 30 - 50$ mV
(12,800 – 7,568 MΩ)

V_B (when blocked) = 5-18 mV

Our first important finding is that a current is measured when drops impinge on a bar even if the intact core is not touched.

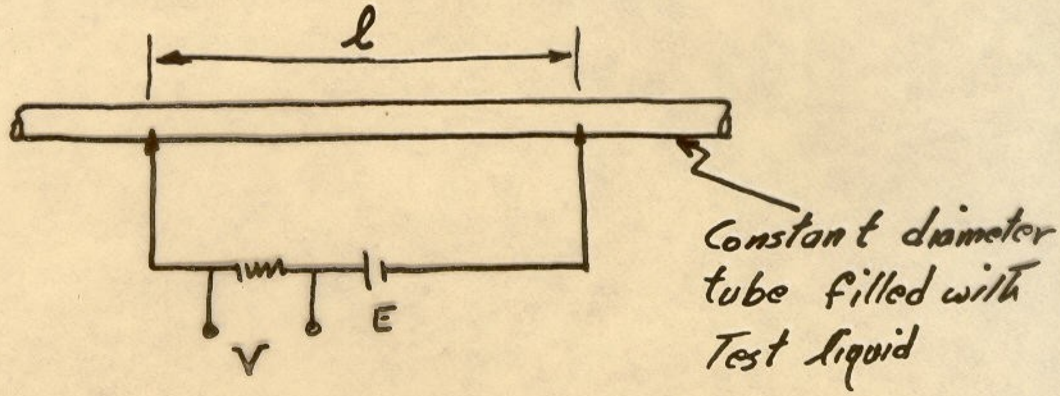
In fact a current is measured also when a spray flows between two needles and the needles themselves are dry.

Thus the current measurement by Hiroyasu does not imply necessarily the existance of an intact core between the nozzle and the measurement station.

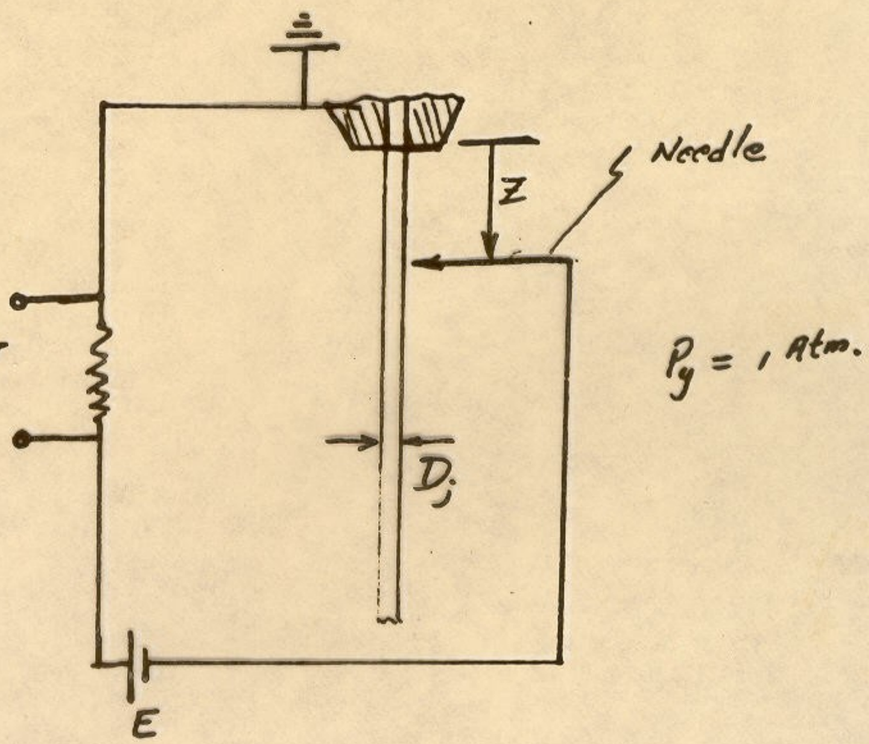
The current carried by the drops, or across the spray, sets a limit also on our own measurements which will be discussed later.

In our efforts to determine the length and the <u>shape</u> of the core, we first measured the resistance of an intact cylindrical column of water to check and calibrate the system.

Resistivity Measurement

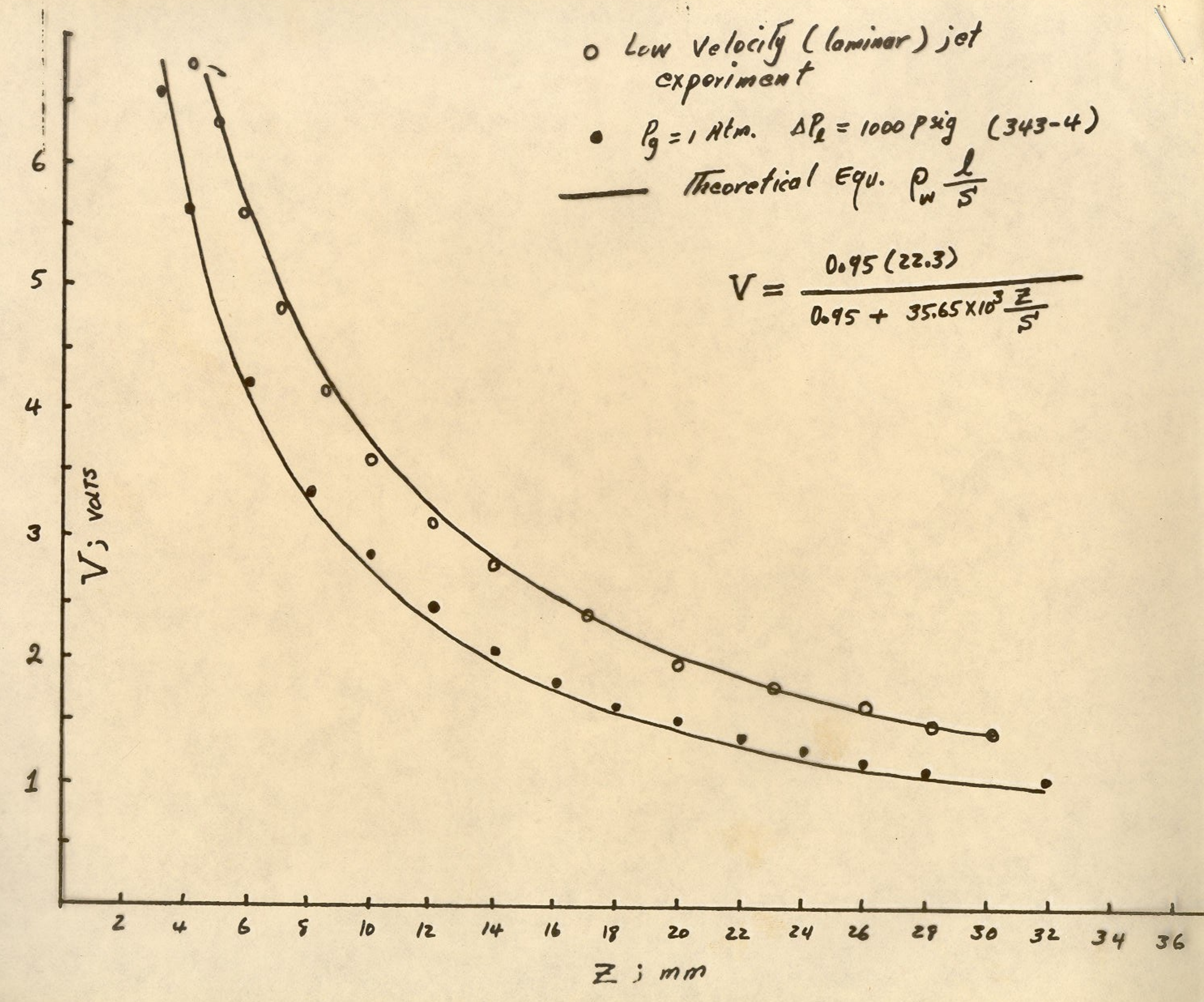


Low Velocity (laminar) jet experiment



Diameter of the jet was measured using 26X magnification camera.

$D_j \simeq 308 \pm 10\ \mu m$ ($D_N = 343\ \mu m$)



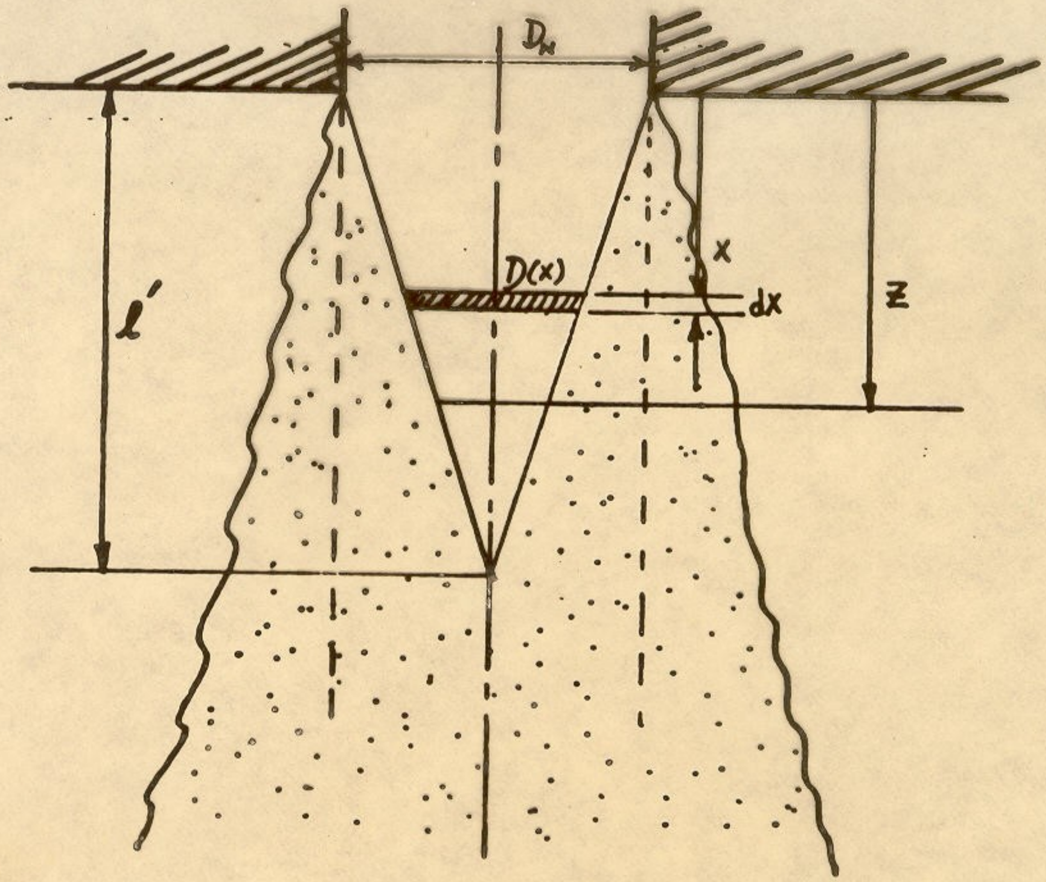
o Low Velocity (laminar) jet experiment
• Pg = 1 Atm. ΔPl = 1000 psig (343-4)
Theoretical Equ. Pw l/S'
V = 0.95 (22.3) / (0.95 + 35.65 x 10^3 Z/S')
V; volts
Z ; mm
1
2
3
4
5
6
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36

Conclusion (so far!)

Resistance equ. ($\rho \frac{l}{s}$) for metalic conductors is also applicable for an intact column of water.

Extension

Since water behaves ... similar to metalic conductor and if there is an intact core of unknown geometry, then a measurement of the resistance of the core at various locations along the jet may lead to its shape.



$$D(x) = D_N\, f(x)$$

$$dR = \rho \frac{dx}{S} \quad ; \quad S = \frac{\pi D_N^2 f^2(x)}{4}$$

$$dR = \frac{4\rho}{\pi D_N^2} \cdot \frac{dx}{f^2(x)}$$

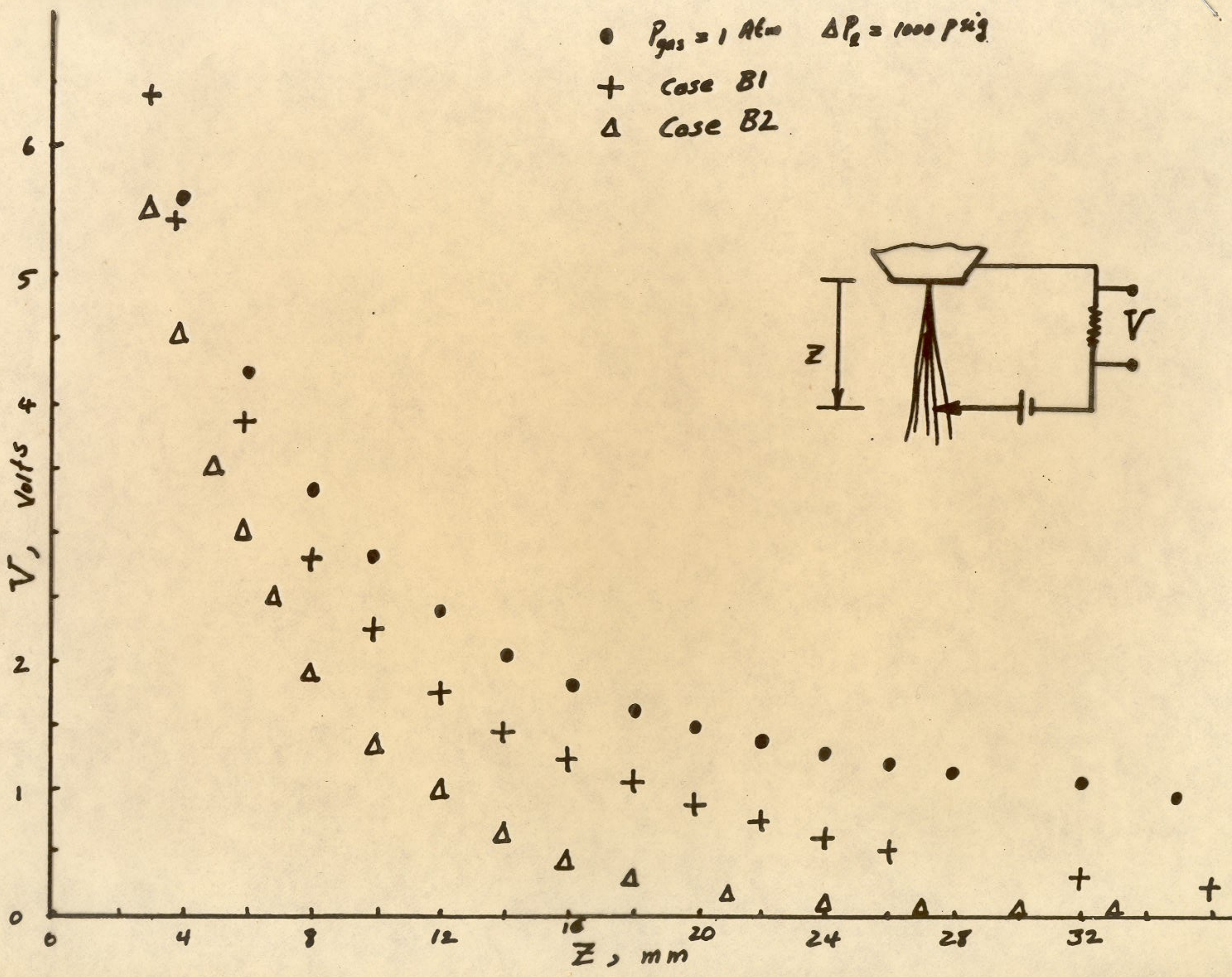
$$\boxed{R_{spray}(z) = \frac{4\rho}{\pi D_N^2} \cdot \int_0^z \frac{dx}{[f(x)]^2}}$$

If linear model : $D_1(x) = D_N \left(1 - x/\ell'\right)$

$$\alpha \equiv R_{spray}(z) \,/\, (4\rho\ell/\pi D_N^2) \equiv \frac{\ell'}{\ell' - Z}$$

Table of Test Conditions

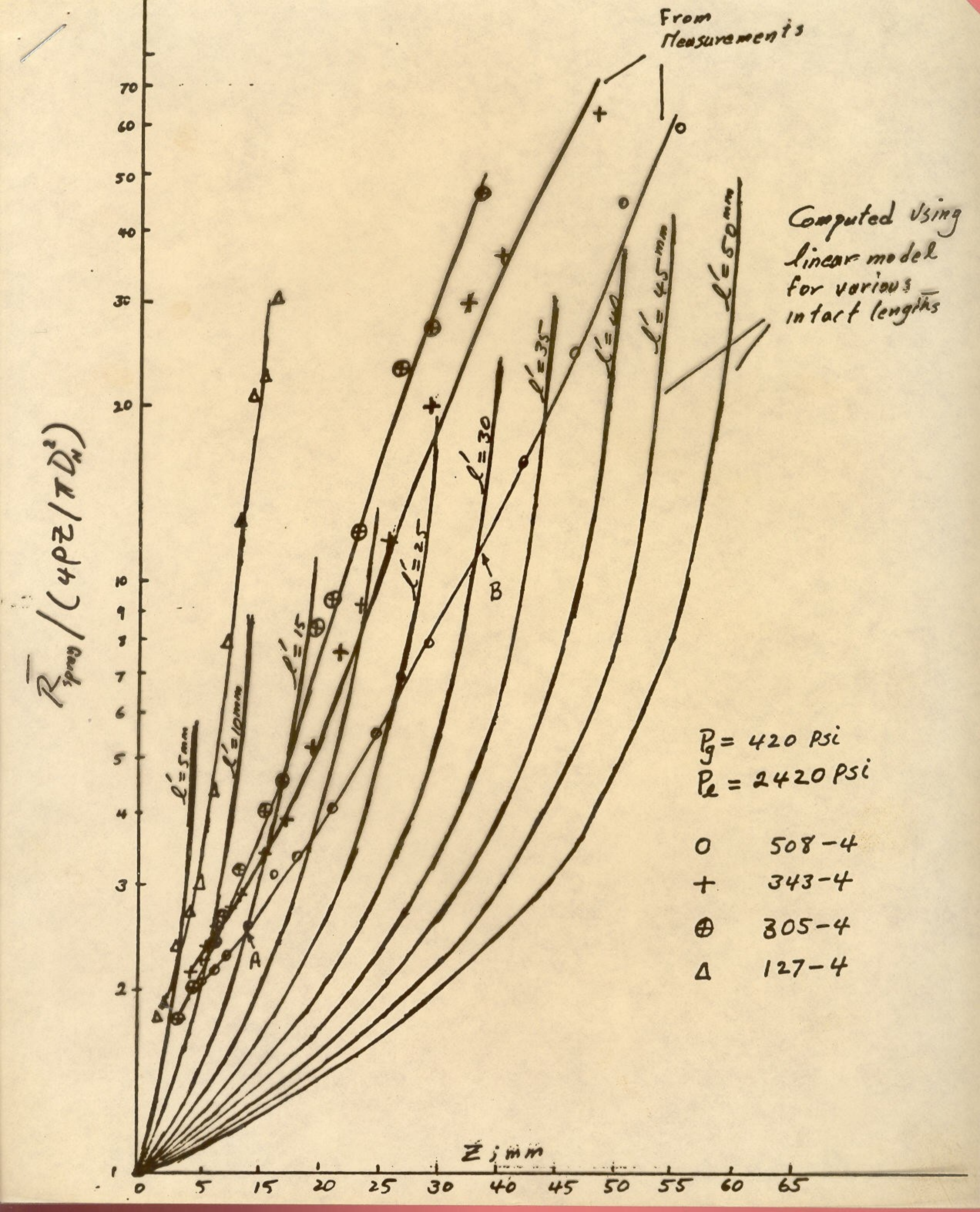
Test Case	Nozzle	Dia – L/D (Dia μm)	Liquid	ΔP_ℓ psig	P_g psig	$\frac{\rho_L}{\rho_g}\left(\frac{Re}{We}\right)^2$
A1	X-9	508-4	H_2O	2000	150	36.6
A2	"	"	"	"	420	14.4
B1	X-8	343-4	"	"	150	36.6
B2	"	"	"	"	420	14.4
C1	X-5	305-4	"	"	150	36.6
C2	"	"	"	"	420	14.4
D1	X-6	127-4	"	"	150	36.6
D2	"	"	"	"	420	14.4



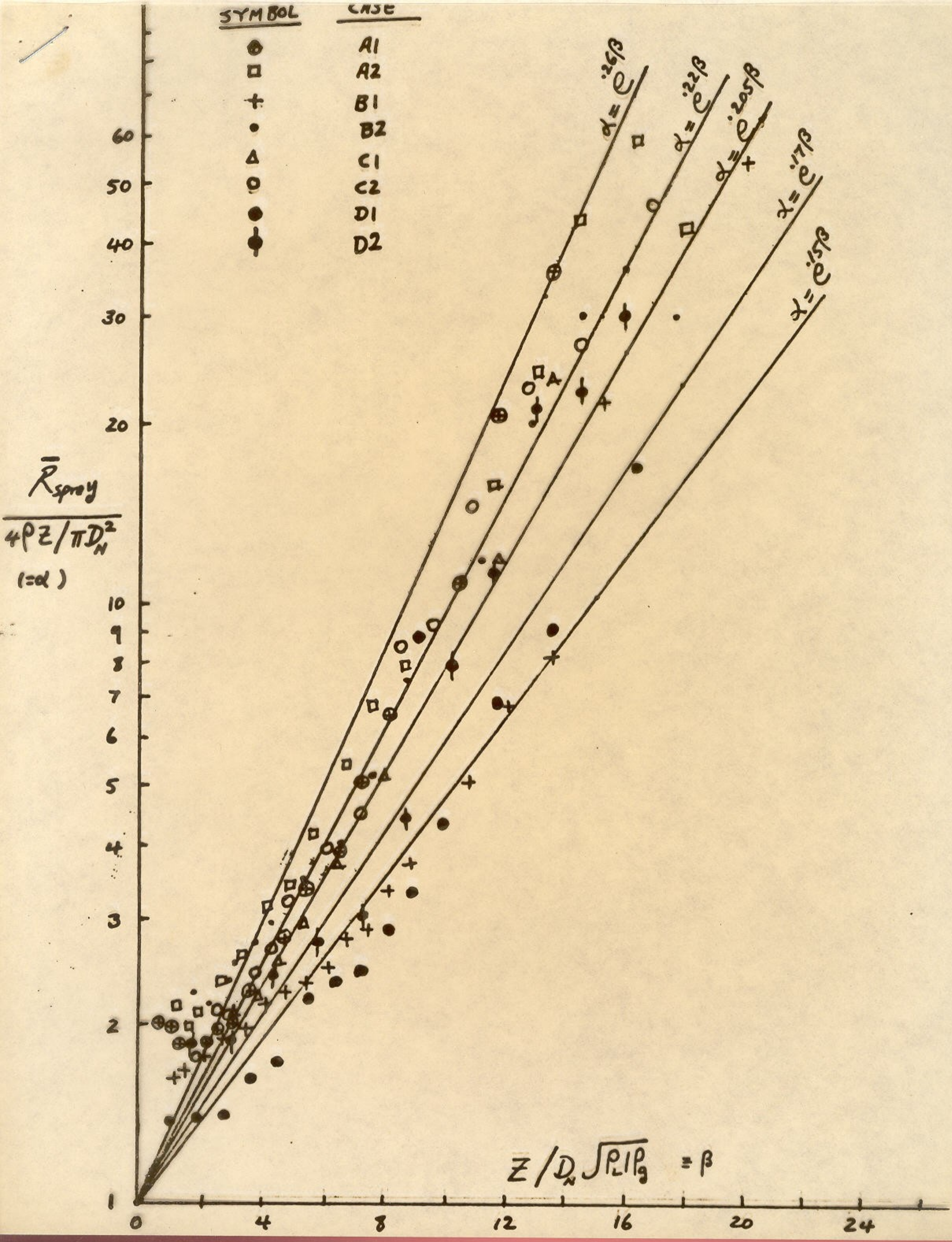
● P_{gas} = 1 Atm ΔP_{ℓ} = 1000 psig
+ Case B1
Δ Case B2
V, Volts
Z, mm
0
1
2
4
5
6
4
8
12
16
20
24
28
32
Z
V

If it is assumed that the intact core is 'triangular in shape. Then one can compute its resistance versus axial distance from the nozzle and compare it with the experimental results.

In the next figure, at "A" the resistance of the intact core is equivallent to the resistance of the frustum of a cone with length of $l' = 15$ mm and similarly at "B" the resistance of the core is equal to the frustum of a cone with $l' = 30$ mm. This indicates that the shape of the core is convex towards the jet axis.



From Measurements
Computed using linear model for various intact lengths
$\bar{R}_{spray} / (4PZ/\pi D_N^2)$
Z ; mm
P_g = 420 psi
P_e = 2420 psi
○ 508-4
+ 343-4
⊕ 305-4
Δ 127-4
l′=5mm
l′=10mm
l′=15
l′=25
l′=30
l′=35
l′=40
l′=45mm
l′=50mm
A
B

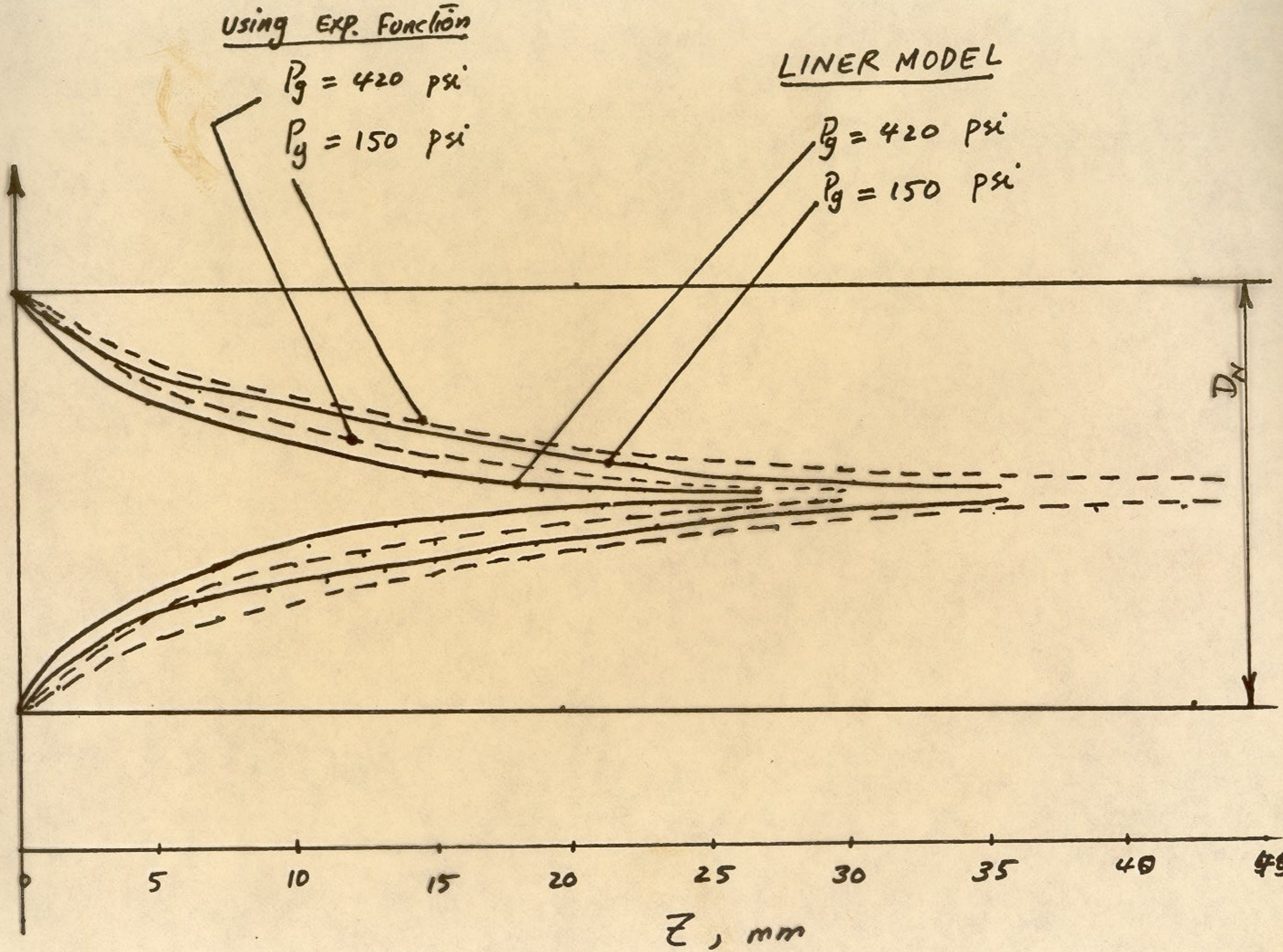

SYMBOL
CASE
A1
A2
B1
B2
C1
C2
D1
D2
$\alpha = e^{.26\beta}$
$\alpha = e^{.22\beta}$
$\alpha = e^{.205\beta}$
$\alpha = e^{.17\beta}$
$\alpha = e^{.15\beta}$
$\frac{\bar{R}_{spray}}{4\dot{\rho}Z/\pi D_N^2}$
$(=\alpha)$
$Z/D_N\sqrt{\rho_L/\rho_g} = \beta$
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
0
4
8
12
16
20
24

An exponential function has been tried for the experimental data in the form $\alpha = e^{a\beta}$ from which one can compute the shape of the core. Results are good for higher pressure but not satisfactory at low chamber pressure particularly near the exit of the nozzle.

One reason for selecting an exponential function of this form is that in the limit as $\beta \to 0$ (close to the exit of the nozzle) $D(x)/D_N \to 1 - z a\sqrt{\rho_g/\rho_L}$. Such a behavior is predicted by the supplemented-aerodynamic theory of the jet breakup in the vicinity of the nozzle exit.

Using $\alpha = e^{a\beta}$ one could derive an equation for the shape of the core as:

$$\frac{D(x)}{D_N} = f(x) = \frac{\exp\left[-\frac{aZ}{2D_N\sqrt{\rho_L/\rho_g}}\right]}{\left[1 + \frac{aZ}{D_N\sqrt{\rho_L/\rho_g}}\right]^{1/2}}$$


Using Exp. Function
P_g = 420 psi
P_g = 150 psi
LINER MODEL
P_g = 420 psi
P_g = 150 psi
D_N
0
5
10
15
20
25
30
35
40
45
Z , mm

CONCLUSIONS

1. Measurements were made of the shape of the intact core in atomizing sprays using a 1mm diameter bar. They indicate that the mean core boundary is convex towards the jet axis. The length of the core - increases with nozzle diameter and - Liquid-to-gas density ratio.

2. The technique used tends to overestimate the length of the core due to the current carried by the charged drops and by the gas-drop mixture.

3. Measurement of the intact length geometry using a sharp needle to locate the core boundary is feasible but only up to 10 to 15 nozzle diameter from the nozzle where the spray interference is negligible.