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Measurement of the Profile of the Gas Jet Target at the Internal Target Area

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Summary

Studies have been made of the density distribution of the gas jet under various operating conditions. Gas was injected through the target nozzle into an evacuated test chamber at temperatures of $24^{o}K$ and $300^{o}K$ and at pressures of 2, 6, and 10 PSIA, corresponding to gas densities of approximately 10^{-7} to 10^{-9} gm/cm^3. Under all of these conditions the jet exhibited a well defined conical shape with a full opening angle that ranged between 20^{o} and 40^{o}.

INTRODUCTION

Since the installation of the gas jet target[1] in the Internal Target Area in June, 1972, the main ring beam intensity has increased 1000fold. In order to maintain a luminosity tolerable to target particle recoil experiments in the low t region, it has become necessary to continuously reduce the density of the gas jet. Reduced density has been achieved by reducing the pressure of the gas to the target nozzle. The question has recently arisen as to whether a well shaped supersonic jet is maintained at these pressures, and what the low pressure limit might be.

If a well shaped jet at low density could, in fact, be maintained, there is the possibility that the cryopump might be eliminated in favor of a high speed diffusion pump (or turbo molecular pump) at enormous saving in complexity and cost.

An attempt, therefore, has been made to understand low density operation of the jet, in particular, the jet profile dependence on the pressure and temperature of the gas to the nozzle. Since the gas nozzle does not have the form of a true deLaval nozzle, it is not known at what pressure the supersonic flow breaks down and the gas simply diffuses from the orifice.

Direct measurements of the jet profile were made using a constant temperature hot wire anemometer.[2] The anemometer wire was moved through the jet to get a series of horizontal density profiles at various vertical distances from the jet nozzle. Such profiles were made down to the lowest gas pressures possible with the present jet controls, (∼2 PSIA).

APPARATUS

The hot wire anemometer used in these measurements is essentially as described in Ref. 1. The circuitry is shown in Fig. 1. The probe consists of a 5 micron platinum coated tungsten wire which forms one leg of a wheatstone bridge. The bridge is balanced with current in the probe wire sufficient to maintain a temperature of around 700^{o}K. As the jet gas moves past the wire, energy removed by molecular collisions cools the wire reducing its resistance. A differential amplifier across the bridge senses the imbalance and causing a feedback signal to be generated which increases the voltage at the top of the bridge. A scope triggered by the gas jet pulse records a trace of the time variation of the voltage on the bridge. The traces were photographed with a polaroid scope camera.

The setup is shown in Fig. 2. The jet assembly was set on a test chamber containing several ports. Six inch beam pipe flanges on each side of the chamber simulated the configuration of the jet in the tunnel. A 2400 l/s diffusion pump with baffle was connected through a pneumatic valve to the system.

The anemometer probe was attached to a steel dowel mounted on a double "O" ring seal in one of the test chamber ports that viewed the nozzle. The wire, oriented transverse to the dowel, could be moved in the horizontal plane past the nozzle. The jet nozzle itself could be moved vertically to allow measurements in different horizontal planes. Shielded leads connected the probe wire to the amplifier and control chassis.

MEASURING PROCEDURE

For all measurements the jet pulse duration was 50 msec. The pulse was obtained by opening valve V1 for 50 msec followed by a 200 msec opening of V2 to replenish the 175 cm^3 buffer volume between V1 and V2 (see Fig. 2). The oscilloscope sweep was initiated at the opening of valve V1. The vertical input to the scope was connected to the bridge as shown in Fig. 1. A D.C. offset at the scope vertical amplifier permitted observation only of exclusions in the voltage to the bridge.

A profile measurement was made by photographing a series of scope traces, each corresponding to one jet pulse at a new horizontal position across the jet. The probe was typically moved to 12 positions, 2 mm apart, with half of the positions on one scope photograph. Figure 3 shows two typical photos of the data. The photo of the first set of traces was made with the jet at room temperature and the second with a liquid helium filled jet. The large background in the room temperature measurements is eliminated when the jet is cooled and the jet gases are very rapidly pumped by the cryopump.

The voltage excusions ΔV were taken from the photos of the scope traces at one particular time point. The density of particles hitting the anemometer wire is proportional to the power, ΔP, fed to the wire. The relationship between ΔP and ΔV is given by

$$\Delta P = \frac{R_o}{(R+R_o)^2} \left(2V_o(\Delta V) + (\Delta V)^2\right)$$

where R_o and R are the resistance values of the legs of the bridge as shown in Fig. 1, and V_o is the quiescent voltage at the top of the bridge.

The following table shows the jet condition for the measurements that were made. With this apparatus it is possible to make a calculation of the gas density based on a model of the interaction of the gas molecules with the wire.[2] For the limited purposes of this note, however, a rough extrapolation has been made from measurements during earlier jet studies and in the course of experiments using the jet.[1,3,4]

Temp (^oK)	Pressure (PSIA)	Approx. Density (gm/cm^3)
24	10	3×10^{-8}
24	6	2×10^{-8}
24	2	7×10^{-9}
300	10	8×10^{-9}
300	6	6×10^{-9}
300	2	2×10^{-9}

RESULTS

The data are tabulated in Figs. 4 and 5. From these measurements of ΔV, each ΔP (relative density) was calculated and plotted against probe position for each traversal of the jet. Figure 6 shows the profiles for a typical measurement.

Assuming that the gas jet has cylindrical symmetry, we can define a gas density, $\rho(r,Z)$, where r is the radial coordinate in a plane perpendicular to the jet axis and at a distance Z from the tip of the nozzle. The anemometer signal, ΔP, does not measure $\rho(r,Z)$ directly, but rather the line integral of

ρ along the wire direction (length L), i.e.,

$$\Delta P(y,Z) = C \int_{-L/2}^{L/2} \rho(\sqrt{x^2+y^2}, Z)\, dx$$

for a wire parallel to the x-axis at a distance y from the jet axis. Figure 6 is a plot of $\Delta P(y,X)$ vs. y for four values of Z. This integral is of course the "thickness" of the jet target as seen by the proton beam, so Fig. 6 gives the relative target thickness as a function of horizontal and vertical coordinates with respect to the tip of the nozzle. A solid state detector looking at the energy distribution of pp elastic recoils near $\theta_{lab} = 90^{\circ}$, measures more nearly $\rho(r,Z)$, assuming that the proton beam is centered on the jet axis and that the width of the proton beam is small compared to the width of the jet.

For a given Z, $\Delta P(y)$ and $\rho(r)$ will in general not have the same shape; a Gaussian distribution is an exception to this rule. The profiles shown in Fig. 6 are not Gaussian; it is easy to show that for a variety of reasonable distributions for $\rho(r)$, the FWHM of $\Delta P(y)$ and $\rho(r)$ are not very different--perhaps 15% at most.

In Fig. 7 we plot FWHM of $\Delta P(y,Z)$ as a function of Z for the various jet conditions. These plots indicate that the jet is approximately conical in shape with a full opening-angle in the range 20°-40°, the low temperature jet appearing to be somewhat narrower.

ACKNOWLEDGEMENT

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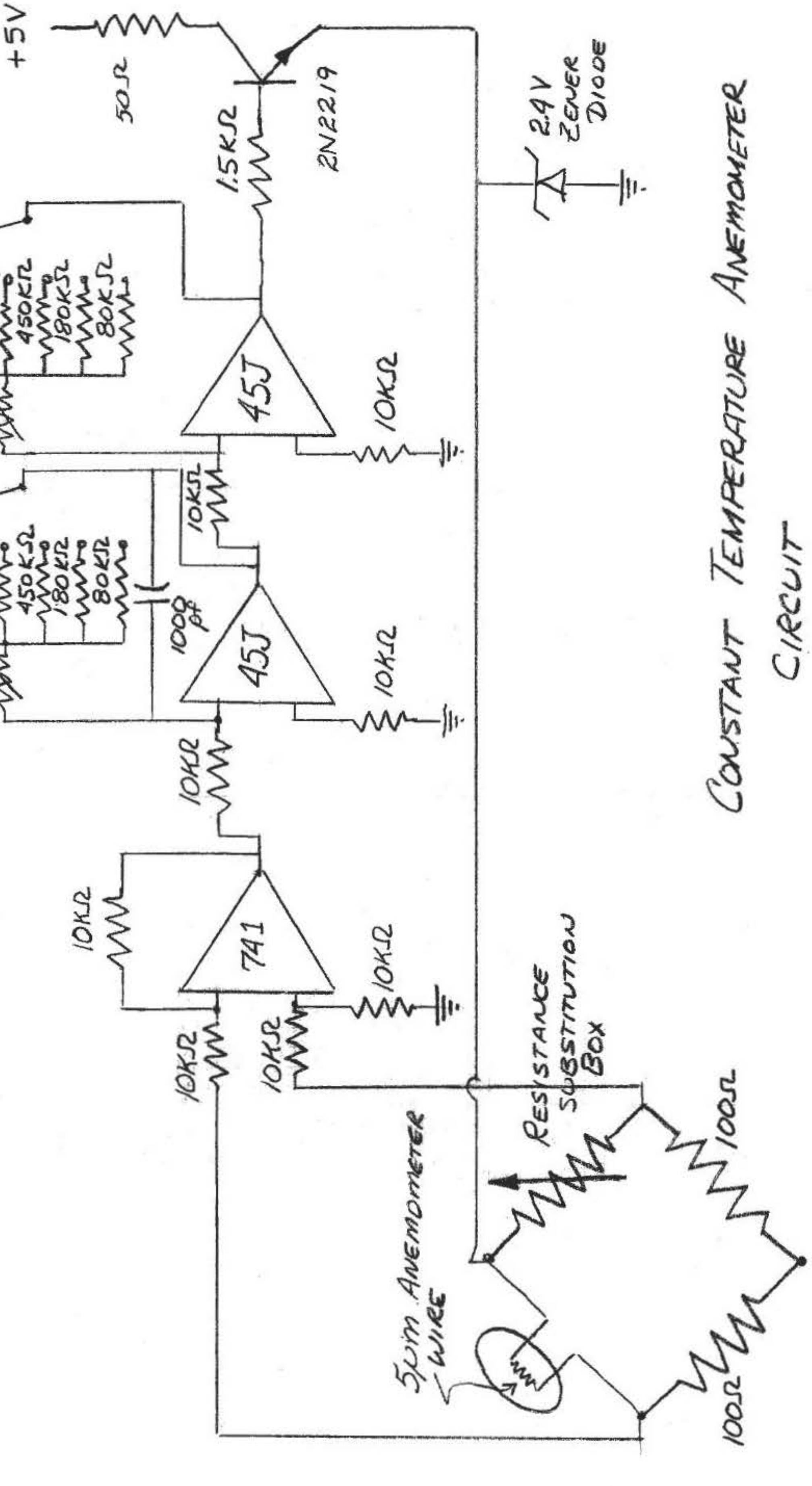
References

1) V. Bartenev et al., "Cryopumped, Condensed Hydrogen Jet Target for the N.A.L. Main Accelerator". Advances in Cryogenic Engineering, Vol. 18, p. 460. Plenum Press, New York 1973.

2) D. Gross and A. Melissinos, "Production of a High Density Hydrogen Gas Jet", University of Rochester report UR-875-365 (unpublished).

3) D. Gross, "Low Momentum Transfer Proton-Proton Elastic Scattering up to 400 GeV", Ph.D. Thesis, University of Rochester, COO-3065-94 (1974).

4) L. Golovanov et al., "Evaluation of the Possibility of Cryopumping Helium Jet by Means of a Parallel Stream of Hydrogen Condensing on a $4.2^{o}K$ Surface", FNAL report TM-515 (1974).



CONSTANT TEMPERATURE ANEMOMETER CIRCUIT

FIGURE 1

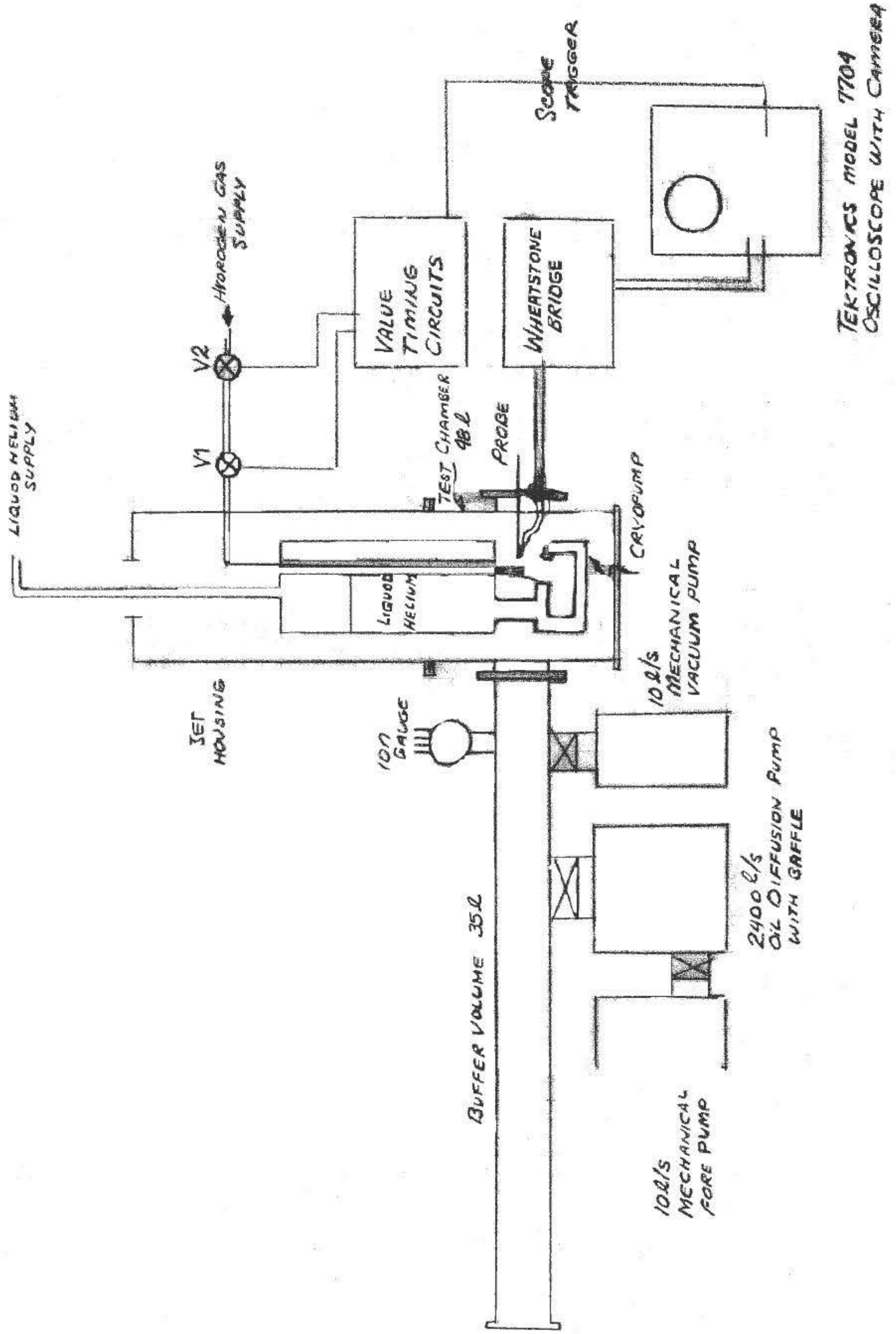
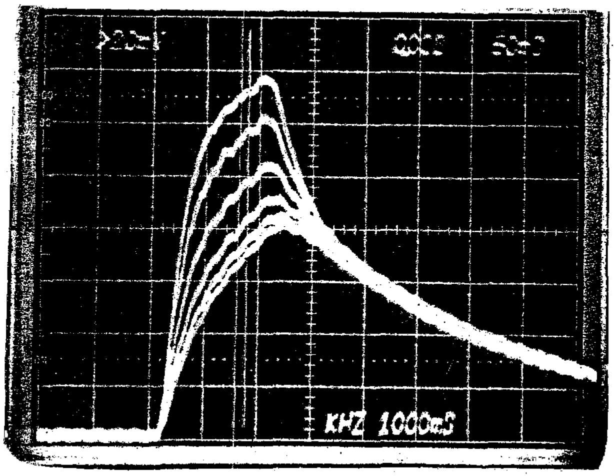
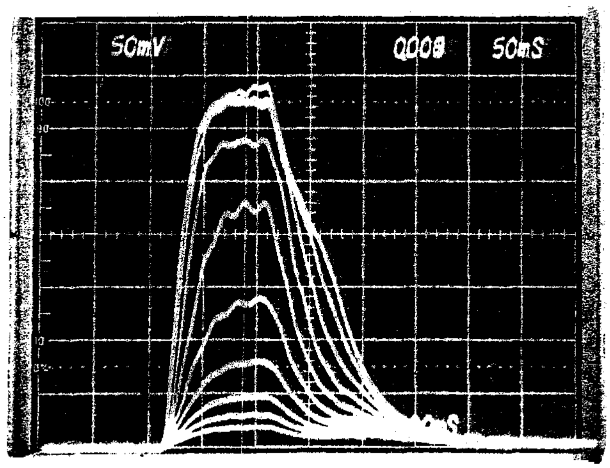

LIQUOD HELIUM SUPPLY
HYDROGEN GAS SUPPLY
V1
V2
VALUE TIMING CIRCUITS
WHEATSTONE BRIDGE
SCOPE TRIGGER
TEKTRONICS MODEL 7704 OSCILLOSCOPE WITH CAMERA
TEST CHAMBER 48 ℓ
PROBE
CRYOPUMP
LIQUOD HELIUM
JET HOUSING
ION GAUGE
10 ℓ/s MECHANICAL VACUUM PUMP
2400 ℓ/s OIL DIFFUSION PUMP WITH GAFFLE
BUFFER VOLUME 35ℓ
10ℓ/s MECHANICAL FORE PUMP

FIGURE 2



ROOM TEMPERATURE JET

PRESSURE: 10 PSIA
TEMP: 300°K



COLD JET

PRESSURE: 6 PSIA
TEMP: 24°K

FIGURE 3

TYPICAL OSCILLOSCOPE PHOTOGRAPHS OF VOLTAGE EXCURSIONS ON THE WHEATSTONE BRIDGE

FIGURE 4

TABLE OF ΔV IN MILIVOLTS

GAS TEMPERATURE 300°K (WARM TARGET)

Hor wire pos (mm)	GAS PRESSURE 2PSIA	6PSIA			10PSIA	
	Z= 5.8 mm	Z= 5.8mm	10.9mm	16mm	Z=10.9mm	Z=16mm
-16						
-14						
-12						
-10			43	44	85	100
-8	8	37	46	50	89	104
-6	9	42	51	54	96	117
-4	11	55	64	60	117	136
-2	15	82	78	70	160	160
0	18.5	132	91	75	192	176
2	17.5	100	84	77	187	168
4	15	62	71	68	152	155
6	11	48	60	60	117	128
8	9.5	41	48	55	101	109
10		39	44	50	91	99
12						
14						
16						

FIGURE 5

TABLE OF ΔV IN MILIVOLTS

GAS TEMPERATURE: 24°K (COLD TARGET)

Hor. wire pos. (mm)	GAS PRESSURE: 2 PSIA					6 PSIA				10 PSIA	
	Z=5.8mm	Z=10.9	Z=16.0	Z=21.1	Z=28.7	Z=10.9	Z=16.0	Z=21.1	Z=28.7	Z=21.1	Z=28.7
											40
-20										30	55
-18									30	50	80
-16				7			10	20	35	65	110
-14			6	8	12.5	10	30	30	47	100	170
-12		8	8	12	14	20	50	45	70	180	270
-10	4	12	10	16	17.5	40	90	75	105	320	330
-8	6	17	18	24	21	90	180	135	165	380	340
-6	12	32	26	32	25	250	300	225	223	430	360
-4	30	59	42	44	29	400	370	285	255	465	380
-2	94	105	65	56	33	485	395	325	275	485	390
0	150	110	88	64	37	485	405	335	275	490	400
+2	61	62	72	55	36	460	385	325	265	485	400
+4	22	34	47	44	33	380	340	305	255	445	385
+6	8	20	34	32	28	230	295	255	240	410	365
+8	4	12	30	24	24	100	180	230	225	370	340
+10		8	28	16	20	50	105	140	187.5	330	310
+12		6	26	12	16	20	60	90	135	210	280
+14				8	13		40	60	95	140	200
+16				6	10		30	38	65	90	140
+18							20	20	45	60	100
+20										50	70
											50

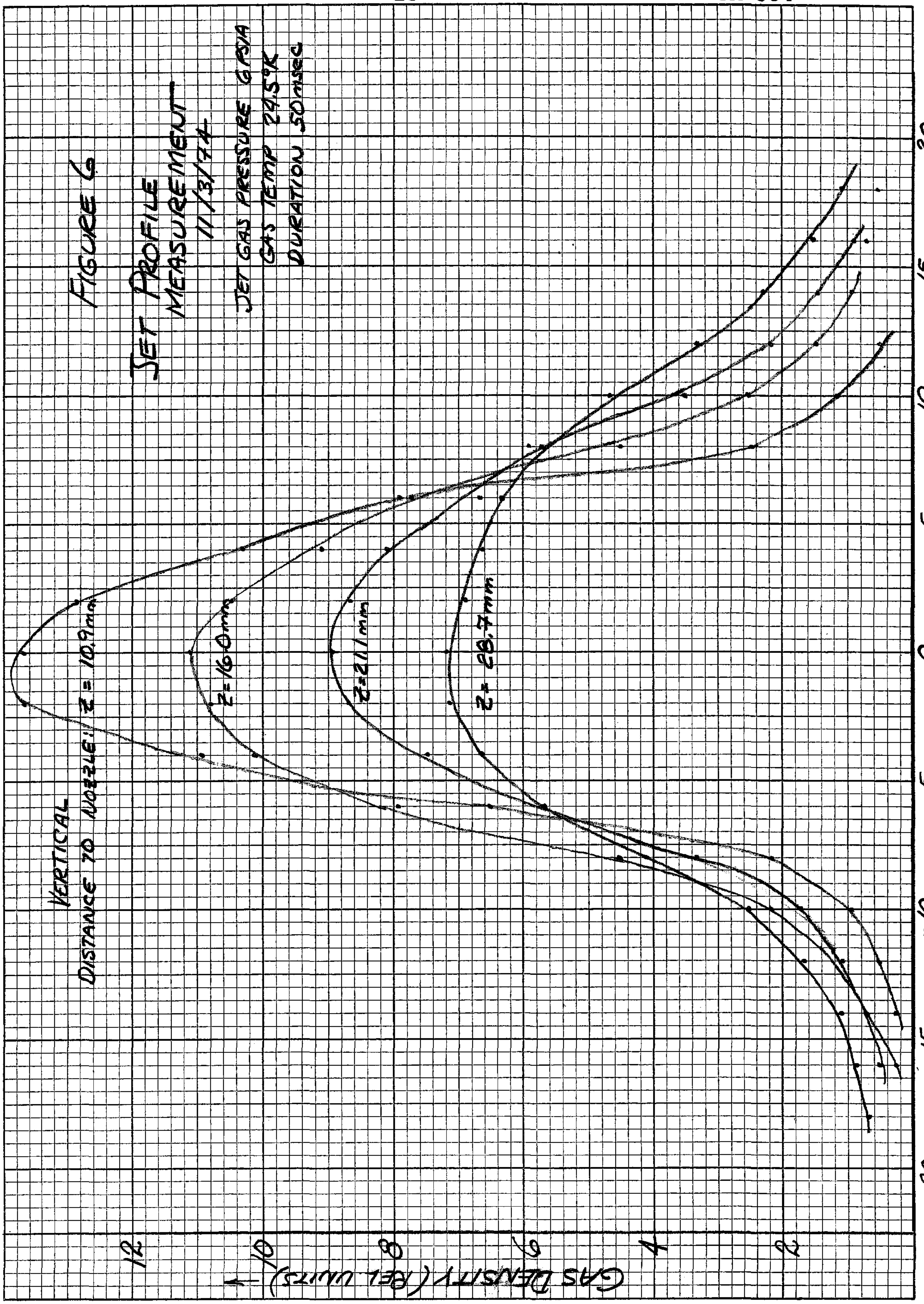
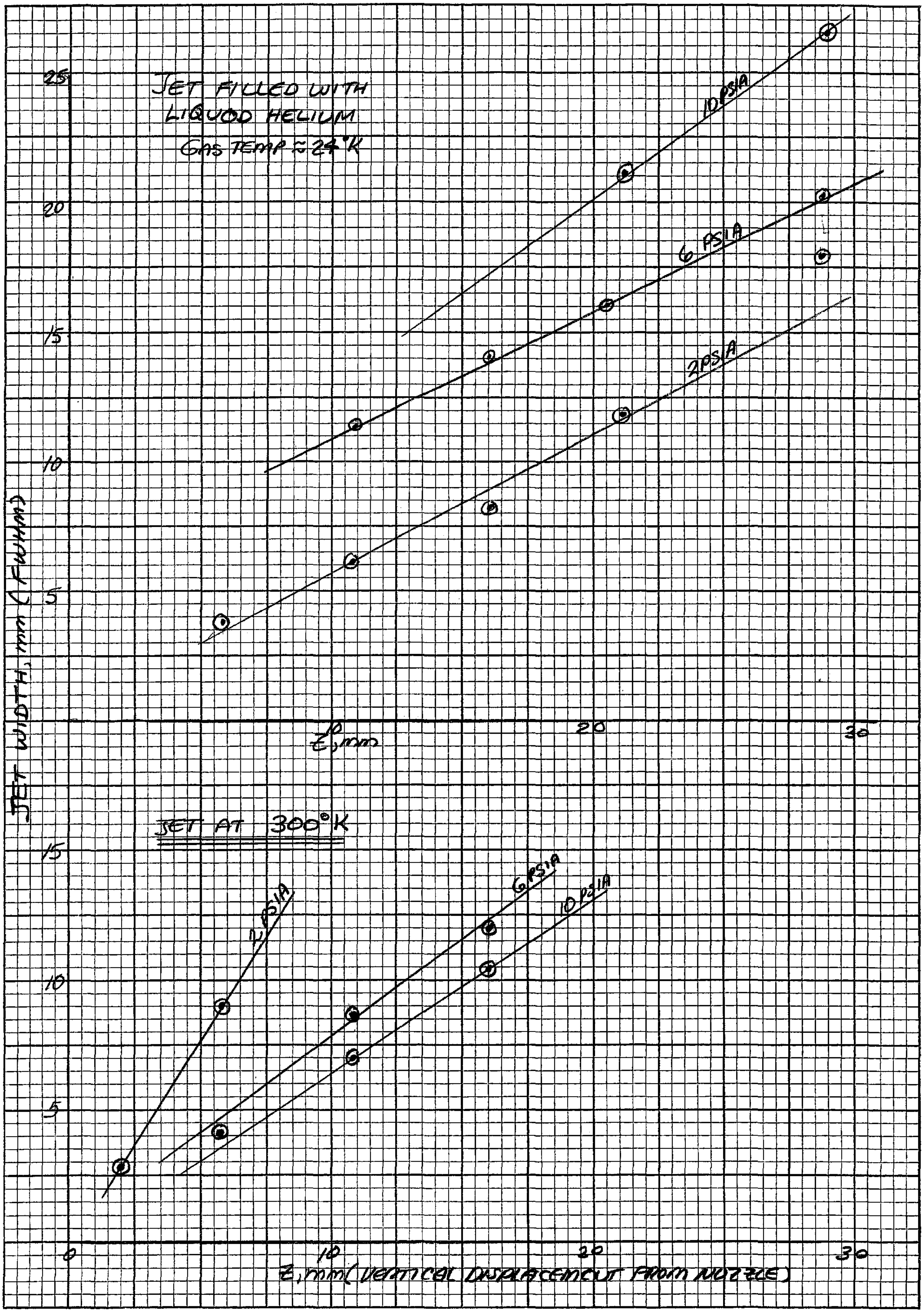


FIGURE 6
JET PROFILE
MEASUREMENT
11/3/74
JET GAS PRESSURE 6 PSIA
GAS TEMP 24.5°K
DURATION 50 msec
VERTICAL
DISTANCE TO NOZZLE: Z = 10.9 mm
Z = 16.0 mm
Z = 21.1 mm
Z = 28.7 mm
HORIZONTAL POSITION (mm)
GAS DENSITY (REL UNITS)
20
15
10
5
0
-5
-10
-15
-20
12
10
8
6
4
2


JET FILLED WITH
LIQUID HELIUM
GAS TEMP ≈ 24°K
10 PSIA
6 PSIA
2 PSIA
Z, mm
JET AT 300°K
2 PSIA
6 PSIA
10 PSIA
JET WIDTH, mm (FWHM)
Z, mm (VERTICAL DISPLACEMENT FROM NOZZLE)
0
10
20
30
5
15
25