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HAZARDOUS GAS LEAK ANALYSIS IN THE SPACE SHUTTLE

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ABSTRACT

This study focuses on helium tests of the main propulsion system in the space shuttle and on hydrogen leaks. The hazardous gas detection system (HGDS) in the mobile launch pad uses mass spectrometers to monitor the shuttle environment for leaks. The mass spectrometers are fed by long tubes to sample gas from the payload bay, mid body, aft engine compartment and external tank. The overall purpose of this study is to improve the HGDS, especially in its potential for locating cryogen leaks.

Pre-existing leak data was analyzed for transient information to determine if the leak location could be pinpointed from test data. Then, a rapid-response leak detection experiment was designed, built, and tested. The apparatus included a Perkin Elmer MGA-1200 mass spectrometer, an air velocity transducer, and a pressure transducer, all monitored by a Macintosh IIFX computer using LabVIEW software. A jet of helium flowing into the lab air simulated a gas leak. Schlieren imaging and video recordings were also employed to study the jet flow phenomena. Steady and pulsed jets were logged for concentration, velocity, and pressure, and the power spectral density of each was computed.

Large eddies and vortices were visually seen with Schlieren imaging, and they were detected in the time plots of the various instruments. The response time of the MGA-1200 was found in the range of 0.05 to 0.1 sec. Pulsed concentration waves were clearly detected at 25 cycles per sec. by spectral analysis of MGA data. One practical consequence of this study is to suggest that the backup HGDS sampling frequency should be increased above the present rate of 1 sample per second.

SUMMARY

This study focuses on helium tests of the cryogenic propellant system in the space shuttle and on hydrogen leaks. The hazardous gas detection system (HGDS) in the mobile launch pad uses mass spectrometers fed by long gas sampling tubes to monitor the payload bay, mid body, aft engine compartment and external tank. The mass spectrometers continuously assay the shuttle environment for hydrogen, helium, oxygen and argon. The overall purpose of this study is to improve the HGDS, especially in its potential for locating cryogen leaks.

Specifically, the present HGDS was reviewed and pre-existing leak data was analyzed for transient information to determine if the leak location could be pinpointed from test data. Spectral analysis was performed on earlier data measured at the OPF and in the Hazardous Gas Detection Lab. Then, a rapid-response leak detection experiment was designed, built, and tested. The apparatus included a Perkin Elmer MGA-1200 mass spectrometer, an air velocity transducer, and a pressure transducer, all monitored by a Macintosh IIFX computer using LabVIEW software. A jet of helium flowing into the lab air simulated a gas leak. Schlieren imaging and video recordings were also employed to study the flow phenomena. Experiments on leak jet characterization included velocity, pressure and concentration profiles and in particular on rapid fluctuations of these variables. Steady and pulsed jets were logged for concentration, velocity, and pressure, and the power spectral density was computed for each observation.

The LabVIEW software performed well in both analysis of earlier data and in real-time data acquisition and reduction. The air velocity transducer (TSI) and the pressure transducer (Rosemount) were capable of measuring rapid transients in helium jet phenomena, and it has the versatility and potential to be applied to leak detection and location. Particular emphasis was centered on large eddies and vortices in the jet-air mixing

zone. Large eddies and vortices were visually seen with Schlieren imaging, and they were detected in the time plots of the various instruments. The response time (63.2%) of the MGA-1200 was found in the range of 0.05 to 0.1 sec., and possibly lower. Pulsed concentration waves were clearly detected at 25 cycles per sec. by spectral analysis of MGA data. For certain, the MGA is fast enough to detect transients such as hydrogen or helium eddies in the time trace data, if sampled at say 50 Hz. Spectral analysis showed some evidence of correlated power in the 0.1 to 20 Hz. region, but visual and transient concentration observations indicated that eddy shedding from the leak jet is somewhat irregular in time. Thus, such events may not correlate well as a definite peak in a power spectral density plot. One practical consequence of this study is to suggest that the backup HGDS sampling frequency should be increased above the present rate of 1 sample per second.

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I INTRODUCTION

In the space shuttle, hydrogen and oxygen are the main engines propulsion gases, as well as the fuel-cell power system gases. Leaks of these gases may be found in the aft fuselage, the mid body, and other areas. Other hazardous gases in the shuttle include nitrogen tetroxide, monomethyl hydrazine, and hydrazine. Various forms of leak detection equipment are employed in and around the shuttle wherever hazardous materials are present. The hazardous gas detection system (HGDS) uses mass spectrometers fed by long gas sampling tubes to monitor the payload bay, mid body, aft engine compartment, and external tank. The mass spectrometers in the HGDS system continuously monitor the environment for hydrogen, helium, oxygen and argon. A detailed account of the HGDS including development of the helium signauture test for the orbiter main propulsion system was presented by Bilardo and Izquierdo in 1987 (1).

This study will focus on helium tests of the cryogenic propellant system and on hydrogen leaks. Helium signature tests are routinely performed to determine the shuttle's cryogenic system integrity. These tests are scheduled at the OPF and the launch pad previous to the start of countdown. Also, catalytic hydrogen detectors inside and around the shuttle are monitored for possible leaks during the countdown period.

Main Goals of Present Study:

1. Assess the present HGDS and analyze earlier leak data to determine if the leak location can be pinpointed from test data.
2. Analyze lab test and OPF helium leak data with LabVIEW software to determine if frequency analysis has meaningful information.
3. Design, build, and test a rapid-response leak detection experiment which focuses on leak characterizaton including velocity, pressure and concentration profiles and in particular on rapid fluctuations of these variables.
4. For a longer-term objective: Predict an improved placement of sample tubes and improved data analysis for special tests (leak events, etc.) so that leak source locations can be identified from frequency analysis of mass spectrometer data.

II BACKGROUND

2.1 PRESENT SYSTEM DEFINITION

The backup hazardous gas detection system draws gas samples in 0.18-in. ID tubes to a Perkin Elmer MGA-1200 mass spectrometer (MS). The MS is a magnetic sector, fixed collector, turbo-pumped instrument, performing 1-sec. per channel analysis (but capable down to 0.02 sec. samples). The MS is situated about 200 ft. away on the mobile launch platform. Five gas samples are sequentially assayed for hydrogen, helium, oxygen and argon. The five samples arrive in separate tubes: three from the shuttle, one from the tail service mast, and one from the external tank.

When cryogenic propellants are on board, about 180 lb/min. of gaseous nitrogen purge gas passes from the mid fuselage, including the payload bay (PB) and the mid body (MB), through the 1307 bulkhead into the aft fuselage (Figs. 1 and 2). Sample gases are drawn into 0.23-in. ID SS tubes distributed in the aft area. The payload bay and mid body tubes are located just aft of the 1307 bulkhead. Four tubes which sample the payload bay purge are connected through tees into one tube which is routed through the umbilical disconnect panel (UDP, line 2). Two SS tubes which sample the mid body purge are connected into one tube leading to the UDP (line 4). The pair of aft sample tubes are mixed together and routed to the UDP. The aft sample tubes are located several feet aft of the 1307 BH at the #9 vent doors, thus the aft sample could reflect upstream leaks from the MB and PLB.

The nitrogen purge is flowing at the pad when the cryogenic propellants are loaded into the vehicle. Both hydrogen and oxygen flow inside separate piping systems from the tail service mast to the shuttle aft compartment to the external tank. Before loading cryogens, helium is injected in this piping system with air purge on the outside (1). This type of test is performed once at the OPF and once at the launch pad to determine whether the system is sealed before loading cryogens.

Hence, leaks in the cryogenic piping can be detected via helium tests before loading cryogens, and by hydrogen and oxygen detection during and after these are loaded on board. Due to safety considerations, the present study was done exclusively with helium, although hydrogen can be easily implemented in future work.

2.2 EARLIER KSC WORK RELATED TO HAZARDOUS GAS DETECTION

In 1990, Schleier studied gas leaks of helium, nitrogen, and argon by flowing the gases through a slightly cracked gate valve (2). Using helium at 68 psig and 105 sccm as the reference condition, flows of helium, nitrogen, and argon correlated well as predicted vs. observed flows. However, the correlation had a slope of 0.9 and an intercept of 15 sccm, which means the predictions will be high at leaks aroung 15 sccm. Further analysis by the present author showed that the individual gas curves for predicted vs. observed were quite different. The end result is that the correlation could give false predictions, either high or low, on the order of 50% error in the range of the flows observed in the lab, and possibly worse errors outside of the data range.

Mehta characterized a turbomolecular-pumped magnetic sector mass spectrometer in 1988 working with the HGDL (3). The model was Perkin Elmer MGA-1200, the same type which is proposed for the present study (H2S2). Linearity, precision, drift, detection limits and accuracy were found to be acceptable for quantitative analytical determination of hydrogen, helium, oxygen and argon in nitrogen or helium background gases. The 90% rise times for pulse inputs were on the order of one-half second. Kachnic and Raisin in 1988 (4) put a one-second pulse of nitrogen into helium into the Perkin Elmer 17" disconnect mass spectrometer resulted in an 84% peak on nitrogen and a dead time of less than 0.1 sec on the upswing. The downswing started about 0.2 sec late, and took another 0.8 sec. to drop to zero. A one-second pulse of helium into nitrogen rose quickly to 98% in less than 0.1 sec., but it did not fall off from 98% until 3 sec. and it zeroed after another second (4 sec. total). This reference was not thoroughly documented to the extent that the response can be considered accurate, but it gives an idea of one MS observed in the field. A recent internal HGDL study (5) on noise in MGA-1200 reported that the unfiltered 60-cycle and related harmonic rms noise level was on the order of 100 mV, which is consistent with noise observed in the present study (both magnitude and frequency). Both noise and time response will be addressed below.

2.3 LITERATURE SURVEY OF MASS SPECS, JETS AND LEAKS

The following brief literature survey gives an indication that much useful information is available to guide researchers and practitioners in leak detection. Only the highlights are presented since the body of literature is beyond the scope of a short-term project. The information on free jets will prove especially valuable in a longer-term study.

2.3.1 MASS SPECTROMETERS.

Mentioned earlier, Mehta made substantial observations in characterizing the MGA-1200 turbo-pumped mass spectrometer (3). Another series of tests with a Leybold helium leak detector are reviewed below (6). In a 1977 KSC report (7), details are given of the UTHE Technology International (UTI) mass spectrometer and related sampling equipment which monitors the main propulsion fuel loading in the space shuttle. This system is the Hazardous Gas Detection System (HGDS) located in the mobile launch pad, also known as the "Prime" mass spectrometer. Of several mass spectrometer texts available at KSC, a good treatment of basic concepts and practical applications is given by J. Roboz (8).

2.3.2 FREE JETS.

A thorough survey of free jet literature was performed because a gas leak is likely to behave in a similar manner to a jet with regard to velocity decay, pressure profile, concentration decay, sonic waves, etc. The rapid, perhaps periodic fluctuations seen in mass spectrometer test data (e.g., Figs. 4 and 5 discussed below) are reminiscent of vortices or large scale eddies which form at the edge of the jet-air mixing zone (9-14). These swirling structures which travel with the jet at roughly the local centerline velocity could give rise to the type of concentration fluctuations which are observed in MS tests of concern here.

Measurements of the mixing of two coaxial hydrogen-air jets are reported by Chriss (15), including centerline decay and radial profile shapes of composition, velocity, and total enthalpy. The striking result is that velocity and composition decay almost identically on dimensionless plots, Fig. 3. Becker et al. (9) worked with an air-air jet marked with oil smoke. Turbulent concentration fluctuations of the nozzle gas diffusing into the stagnant gas were on the order of 25% of the centerline value (lateral distance from centerline about 1/3 of jet radius). Heat transfer and flow measurements including frequency and intermittency data are given by Chua and Antonia (10). Turbulent fluctuations ranged from 10Hz for large peaks to 100 Hz for small variations. Other relevant papers on jets include flow field (16), mixing (17), text-book development and experimental data (18), and imaging of a methane jet (19).

2.3.3 GAS LEAKS.

Researchers in the natural gas industry are quite expert on gas leaks. A review of their techology is helpful in understanding leak and gas phenomena. Examples of publications include AGA Gas Handbook (20), diffusion leak artifacts (21), and Nondestructive Testing Handbook/Leak Testing (22).

III ANALYSIS OF EARLIER TESTS

3.1 LabVIEW SOFTWARE

LabVIEW programs (VI's) writen by Larry Lingvay (Boeing HGDL) were used to analyze existing helium leak data. Most of the data were stored in data files such as Cricket Graph documents which were not compatible with LabVIEW. This problem was solved by reading and editing the data with Microsoft Excel and saving the file as an Excel text file. In this form, the data could be read and processed directly by LabVIEW. (Note that any control headers or column labels must be removed in the editor.) The LabVIEW programs were entitled:

ASCII two 1D arrays2

and *Filtered FFT Read*

The first program opened, read and closed a data file, followed by several operations which created an array from the original data table. This array was transfered to the second program where the data were filtered, the power spectral density (PSD) was computed, and the results were graphed. A number of signal-processing references proved helpful in this phase of the work (23-26). One of particular interest concerned how the eye distinguishes a continuous spectrum of colors with only three types of receptors (cones). Detecting a gas leak with a few sparsely configured sensors is a problem which is similar to the eye mechanism. The key to determining the leak location would be to analyze the time and frequency history of separate sensor locations and overlay the data with logic computations (25).

3.1.1 TEST WAVE.

The LabVIEW programs were validated by running a 1 KHz sine wave as the data file. The results are shown in Fig. 4 for a 1 KHz, 0.1 v peak-to-peak sine wave. The upper plot is the input wave, and the lower plot is the PSD, Watts/Ohm, vs. frequency in Hz. The PSD peak at 1 KHz. indicates that the programs have correctly analyzed the data file. Note that the sampling interval, designated on the lower left part of the plot by "S.INT-delt(sec)" must be entered manually into the control box to the left of this label. In this case the sampling interval is 20 microseconds.

3.2 RESULTS: EXISTING HGDL DATA

3.2.1 SIMULATED LEAKS IN LAB. Helium experiments were performed in March, 1990 in the EDL building. Data were selected from these tests and analyzed with LabVIEW programs discussed above. Two cases were selected to show the capability of the programs to analyze mass spectrometer data. The first was "BLDG FILL" which involved measurements of helium leaking from a jet into rooms 115 and 116 in EDL (DE Haz Gas Lab). The raw data and the PSD are shown in Fig. 5 for a band of data between 1650 and 2200 sec. The initial 500 sec of data were taken in room 116 where the level of helium was 9 to 11 ppm. Later, a fan was set up to mix the helium at the jet orifice with air in room 115. The level of helium there was 35 to 45 ppm. A better picture of the data is obtained if they are separated into three bands, roughly 0-500, 1000-1500,1500 to 2000 sec. Another reason to separate data into bands is to keep them in band widths which have constant sampling frequency. Data such as "BLDG FILL" were sampled at 1.05-sec. intervals but other data are reported at mixed periods from 1.05 to to 21.2 sec. (e.g., "ROOM FILL").

Fig. 6 shows band 1 of "BLDG FILL" in an unfiltered condition. The PSD appears to have some significant peaks from 0.01 to 0.1 Hz. A large amount of data was analyzed, both unfiltered and filtered, but space does not permit including them here. Other data obtained in the HGDL, the ROOM FILL series was analyzed as well. An example of the data in band 4 is shown in Fig. 7 where a small peak at 0.05 Hz appears.

3.2.2 OPF-SHUTTLE HELIUM LEAK SIGNITURE TESTS. An attempt was made (6) in 1990 to show that modified Leybold helium leak detectors could be capable of performing the OPF portion of the orbiter aft helium signiture leak test, *V1201*. If successful, this might eliminate the need for this procedure at the pad, test *V1202*. If *V1202* is still required at pad, the Leybold leak detectors would eliminate the requirement to use the HGDS (U72-1186) to perform the test, reducing manpower and MS service problems caused by excessive oxygen and water in the pad test.

Testing was performed in HB1 of the OPF using the prototype system to characterize helium background in and around the orbiter and at ground level. Also, a demonstration was given in the DE/Haz Gas Lab. Stability and resolution at sub-ppm levels of helium have been shown to be adequate to allow a production version to replace the HGDS (prime) when performing *V1201* or *V1202*, either at the OPF or the pad. The system was relocated to the OPF HB1 for OPF background evaluation testing by ESC personnel.

Frequency analysis of earlier OPF data were also performed as described above for the HGDL data. Fig. 8 depicts a filtered version of helium data from an OPF test on Feb. 23, 1990, taken at a sample period of about 5.4 sec. The low-pass Bessel filter had a cutoff at 0.09 Hz and a frequency resolution of 0.0003 Hz. Again, there does not appear to be a correlated peak on the PSD, with the exception of events around and below 0.011 Hz.

3.2.3 LAUNCH PAD-SHUTTLE HELIUM LEAK SIGNATURE TESTS.

The HGDL files contain results of many helium signature tests on the launch pad. These data can be handled in the same way as discussed above. The results would show periodic events below 1 Hz due to the slow sampling speed of the measurements.

3.3 DISCUSSION OF ANALYSIS RESULTS

The test sine wave showed that the digital computation of power spectral density was accurate, as shown in Fig. 4. Applying this method to data measured in the HGDL and the OPF with the Leybold detector did not result in any obvious characteristic frequencies. Comparing the power spectra in Figs. 5-8 (where *T-Domain Amplitude* is in ppm helium), there are some peaks at frequencies below 0.1 Hz that have correlated power, but the peaks do not stand out above the remainder of the spectra as expected (compare Fig. 4). Furthermore, events at these frequencies represent concentration waves of very long periods, 10 to 500-sec. Since the data were measured in 1-sec. intervals, there can be no meaningful frequencies represented in them above 1 Hz, and to eliminate aliasing, the analysis must be at frequencies below the Nyquist value of one-half of the sampling frequency, or 0.5 Hz.

Data from the OPF have similar characteristics to the above. The only significant power peaks occur at event times between 100 and 400 sec. (i.e., 0.011 to 0.0025 Hz.). Events of such low frequencies could be construed as instrument drift. From another point of view, there may well be slow concentration oscillations due to vorticies shedding off of a jet leak. These events were noticed in new data reported below using Schlieren imaging. The striking thing about Schlieren images is that large, lumbering vortices do in fact peel off from the jet stream, but not at precisely regular intervals. Irregular concentration jumps detected by a sampling tube leading to a mass spectrometer could remain intact and be detected, but the power spectral density would not always show these events as high-dB peaks beacuse they don't occur at regular intervals. Such events occuring at low frequencies below 1 Hz may be more easily detected by observing the time-concentration plot instead of the power density. Another method of analysis would be to take moments of the power such as the product of frequency and PSD. This technique has proved fruitful in other jet studies reported in the literature. A final consideration is that concentration fluctuations caused by flow events such as vortices will occur at frequencies depending on the source-stream velocity, orifice geometry, and macroscale flows such as nitrogen purging. In general, fluctuations caused by jet mixing would be expected to be in the frequency range of 1 Hz or above (c.f., ref. 10).

IV NEW EXPERIMENTS

4.1 SIMULATED HELIUM LEAKS

A helium leak was simulated in the HGD Lab by a pure helium stream (KSC grade) flowing from the lab-service panel through 1/4-in. Tygon tubing, and exiting through a small nozzle. The gas exited the nozzle from a circular orifice, 0.05 cm. diameter, recessed in a short tube, 0.5 cm long and 0.4 cm. diameter. In effect, the jet was actually emerging from the 0.4-cm. tube, at velocities of 10,000 FPM and above.

4.1.1 APPARATUS AND PROCEDURE.

A schematic drawing of the equipment used in the HGDL is shown in Fig. 9. A Rosemount pressure transducer was used to measure pressure fluctuations in the jet field (Minneapolis, MN). This device is capable of measuring pressure from 22 to 32 inches of mercury absolute. Velocity and its fluctuations were detected by a TSI Inc. air velocity transducer with a range of 0 to 10,000 fpm (St. Paul, MN). These probes were mounted on a calibrated X-Y vise which provided an accurate measure of the probe tips in relation to the jet origin.

The jet stream representing the leak was measured and controlled by a Sierra Instruments 840 SideTrak mass flow meter/controller. The instrument was calibrated for nitrogen gas flow, but was correctable to helium gas by multiplying the reading by 1.453 (for units of standard liters per minute). An independent check on the frequency response of velocity, pressure, and concentration measurements was provided by installing in the leak jet a solenoid valve driven by a square wave generator and power supply. Most experiments were done with a steady flow in the leak jet, but selected experiments were done with various pulsed frequencies as noted elsewhere in the text.

In order to observe the leak jet, a Schlieren grating and TV video system was set up. Most experiments were performed with the assistance of this equipment to locate the jet and large vortices which rolled off of the jet. Video recordings were made of the major jet phenomena associated with experiments reported here.

A Perkin Elmer MGA-1200 (H2S2) was employed as the gas analyzer. A sample pump drew 0.2 to 1 liter per minute past a SS tube connector which was specially fitted with a capillary tube to provide a 200 Torr leak to the MS input. The helium jet was sampled with a 0.2-cm. nozzle probe with 7.5 ft.of 1/4-in. ID Tygon tubing leading to the MGA valve #2. Samples were taken at various locations in accordance with the velocity and pressure sampling (x=axial, y=horizontal, z=vertical). Later, a 15-ft. length of 1/32-in. ID SS capillary tubing was fitted to the MGA inlet valve #2. This sample line, excluding the earlier short length of fine capillary tube, was pumped directly with the MGA roughing pump. It turned out that the sampling dead time dropped drastically, as discussed below.

All three sensors were fed into a National Instruments data acquisition board (NB-MIO-16XL-42) plugged into a MacIntosh IIFX computer. A LabVIEW VI called *Super Spectrum Analyzer w/O* sampled, plotted and analyzed the data from each sensor. The analysis routine was to sample during a given time window with a specified number of samples, e.g., 1024, 2048, etc., and then find the mean, standard deviation, and power spectral density. Another version of this VI, *Ultra Spectrum Analyzer/Ave*, was implemented to sum multiple replicate data bands and average the PSD. Specific results of spectrum averaging are not included in this report.

V RESULTS-CHARACTERIZATION OF A HELIUM JET

5.1 FLOW VELOCITY AND VISUALIZATION

Velocity measurements were made first to establish the jet location. The air velocity transducer (AVT) had a very rapid response to flow variations. A typical helium jet of 2.9 SLM flow into air issued from the 0.4-cm. leak orifice at 827 FPM and decayed to 692 FPM at x = 8 cm downstream on the horizontal centerline. Fig. 10 shows the velocity and PSD traces at this point (where velocity in ft/min is equal to 2000 times volts). For comparison, a hydrogen jet (15) under these conditions would decay to about 20% of the initial velocity, or 270 FPM, within 20 orifice diameters (i.e., in this case, 8 cm.). The unsteady nature of the velocity curve indicates the eddy fluctuations in the stream which give rise to +/- 60 FPM changes. Note that this jet, being horizontal, is strongly buoyant. Thus, a measurement on the horizontal centerline is likely to be below the main jet body. In another run, a 1.2 SLM helium jet was pulsed at 5 Hz. (top Fig. 11) and 20 Hz (bottom Fig. 11) to observe the frequency response of the AVT located at x = 2.5 cm on the centerline. Both PSD curves show strong peaks at the forcing frequencies of 5 and 20 Hz., respectively, showing that the AVT had the capability of seeing velocity fluctuations. In a third run, with x = 22 cm., the lateral velocity profile from y = 0.0 to 2.5 cm. showed large fluctuations, on the order of 10 to 100% of the axial flow (e.g., Fig. 12). Meanwhile, the axial velocity decayed from 230 FPM at y = 0, to 26 FPM at y = 2.5 cm. These later data were observed with a jet of 7.4 SLM. A video cassette recording was made in the above experiments as well as others discussed below.

5.2 PRESSURE FIELD

The pressure field in the jet vicinity was sampled at a few locations, mainly in connection with pulsed helium jets. A pressure pulse of 25 Torr was observed 2.5 cm. downstream from a helium jet cycled at 1 Hz. The power spectrum was quite distinctive for pulsed tests of 1, 1.5, and 2 cps. A map of the steady jet field is definitely of interest, but perhaps a more sensitive transducer would be necessary, e.g., full scale range of 50 instead of 250 Torr in the present instrument. In one test at 1.5 cps, the data system was pushed to the upper limit of 50,000 Hz. Fig. 13 shows the time trace expanded and the power density extended to 22,000 Hz. Several significant peaks are evident, at 6K, 12K, 15K, and 20K Hz., which seem to suggest that ultrasound signals found by others near 40K Hz. might be detected with this transducer.

5.3 CONCENTRATION FIELD AND FREQUENCY ANALYSIS

The average helium concentrations vs. distance measured by the MGA-1200 are given in Fig. 14. The standard deviation for these data are on the order of 1% helium due to the noise in the MGA-Macintosh system. As for detecting helium vortices by frequency analysis of the concentration-vs.-time data, the question of response time arises for the sample tube and the MGA-1200. An indication of the mass system response was determined by rapidly thrusting the sample tube from room air into the helium jet. The response curve is shown in Fig. 15. The total sample dead time is not shown on the graph, but it was separately measured at 10 sec. in the 1/4-in Tygon tube of 7.5 ft. The figure shows a 90% rise time of 1 sec., or a peak-to-peak time of 1.3 sec. Because this was considered too slow, modifications were made to incorporate the 1/32-in. capillary sample tube. The helium concentration rise and fall times for a square wave input to the 1/32-in. tube are shown in Fig. 16. The procedure was to place the sample tube at x = 2.5 cm. in the helium jet, then block the tube with a ruler, quickly remove the ruler at time zero, and replace it at 3 sec.

VI DISCUSSION OF NEW EXPERIMENTS

Velocity and Flow Visualization The air velocity transducer was simple and versatile, yielding fast response and easy mapping of the helium jet field. Its frequency response was directly seen by pulsing the jet in selected runs. In steady-jet runs, the PSD showed some 60 Hz. noise and associated harmonics. Schlieren images of the jets indicated that the large eddies or vortices do give rise to large velocity fluctuations, but these do not occur at precisely regular intervals. For this reason, there were no standout PSD peaks, but the vorticies could be seen quite clearly in the time trace of the AVT. Thus, the AVT could be applied to leak detection and to pinpointing leak location if the environment were not overwhelmed by purge gas or physical obstructions.

Pressure The Rosemount pressure transducer was also simple and versatile, with extremely fast frequency response. It was capable of sensing vortices around 1 to 10 Hz., and also able to pick up ultrasound, although in the latter measurements, artifacts of electronic noise could not be ruled out.

Concentration Using Mass Spectrometer From knowledge of the dissipation of a hydrogen jet into air (15), it is reasonable to expect a rapid dissipation of helium jets as well. Our measurements show that the helium jet in terms of velocity persists several times longer downstream than a hydrogen jet, as measured by the variable x/D, the downstream length coordinate divided by the leak orifice diameter. Fig. 15 gives a rough measure of the MGA response, but it contains an error of 0.1 or 0.2 sec which is the time required to move the sample nozzle into the helium jet. Although this appears to be slow for frequency analysis, modifications were made in the sample plumbing which significantly increased the system response. The lower curve, PSD vs. frequency, shows 60 cycle noise and its many harmonics. The substitution of the smaller sample tube decreased the total system dead time (Fig. 16) to roughly 0.2 sec., which is likely to be mainly the sample-tube dead time. The MGA-1200 time constant can be estimated from this figure.

The rise time constant is on the order of 0.05 sec., and the fall time constant is about 0.1 sec. These numbers suggest that the MGA-1200 is capable of detecting fluctuations at or below about 20 Hz. At this writing, another experiment with a pulsed jet resulted in a significant PSD peak at 25 cps which was the pulsing frequency. The 1/32-in. sample tube was situated 2.5 cm. downstream from the jet nozzle within the free jet stream. This again underscores the rapid response of the MGA-1200.

VII CONCLUSIONS AND RECOMMENDATIONS

Conclusions

* The LabVIEW software developed for this work was capable of reading, plotting, and calculating power spectra of digital data. These included earlier helium data at the OPF and HGDL stored on hard disks, and new data acquired and analyzed in real time in the present work. This capability was applied to mass spectrometer, air velocity transducer, and pressure transducer data reported in this work.

* An air velocity transducer (TSI) was capable of measuring rapid transients in helium jet phenomena, and it had the versatility and potential to be applied to leak detection and location.

* An ambient pressure transducer (Rosemount) was capable of sensing rapid pressure phenomena in the helium leak jet, including pressure fluctuations, sound, and ultrasound up to the maximum frequency capability of our present data acquisition system, 25,000 Hz. This may correlate with other reports of ultrasound leak detection near 40,000 Hz. Thus, it may be possible to do leak detection and location with this simple device.

* The response time (63.2%) of the MGA was shown to be 0.05 to 0.1 sec., and possibly lower. Pulsed concentration waves were detected at 25 cycles per sec. using spectral analysis (but no experiment was run above this frequency).

* Vortices and large eddies were visually seen with Schlieren imaging. The MGA-1200 is fast enough to detect transients such helium eddies in the time trace data, if sampled at say 50 Hz. Spectral analysis showed some evidence of correlated power in the 0.1 to 20 Hz. region, but visual and transient concentration observations indicated that eddy shedding from the leak jet is somewhat irregular in time. Thus, such events may or may not correlate well as definite peaks in a power spectral density

plot.

Recommendations

* One practical consequence of this study is to suggest that the backup HGDS sampling frequency should be increased above the present rate of 1 sample per second.

* Also, it would be interesting to do tests like the above using two or more mass spectrometer sample tubes at different locations. These could be monitored sequentially by switching a solenoid valve between tubes. Then, spectral analysis of different tube locations would be analyzed for transient events pointing to the leak location. Such a system could be implemented with the present HGDS sample tubes in the shuttle.

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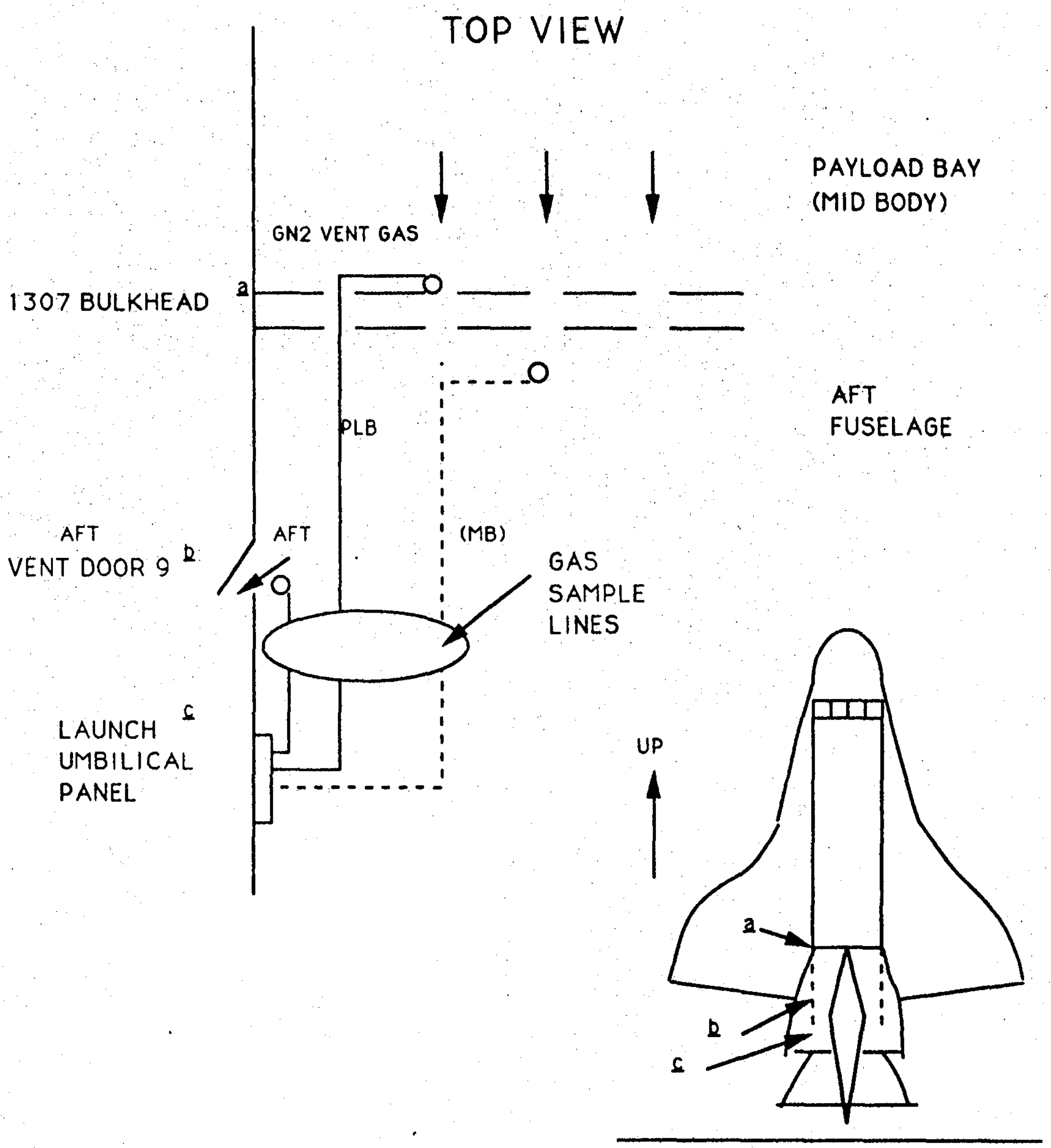

Figure 1. Top view of shuttle showing nitrogen purge areas and HGDS sample tubes

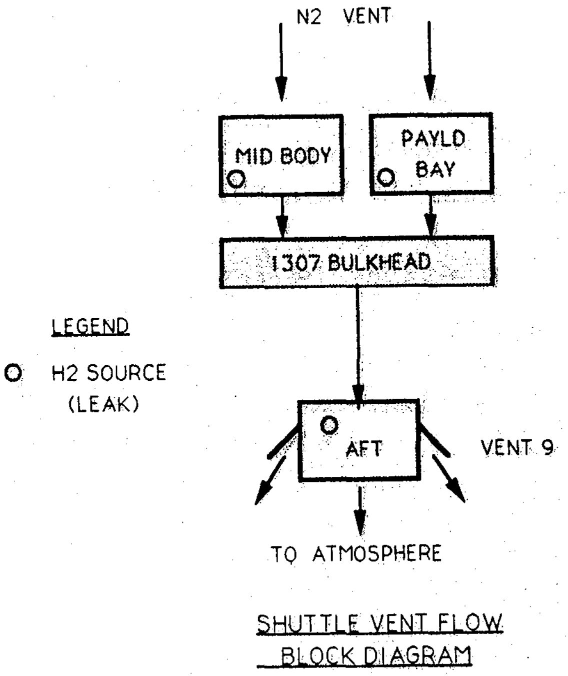

Figure 2. Block diagram of nitrogen purge flow in the space shuttle

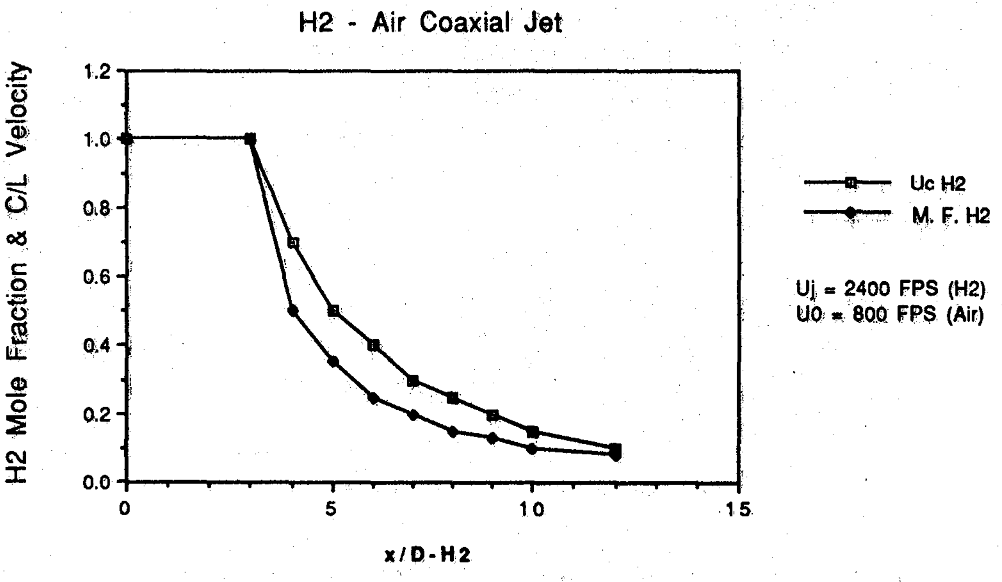

Figure 3. Hydrogen-air coaxial jet showing velocity and concentration decay in the centerline, by Chriss

Filtered FFT Read
Monday, July 1, 1991 3:33 PM

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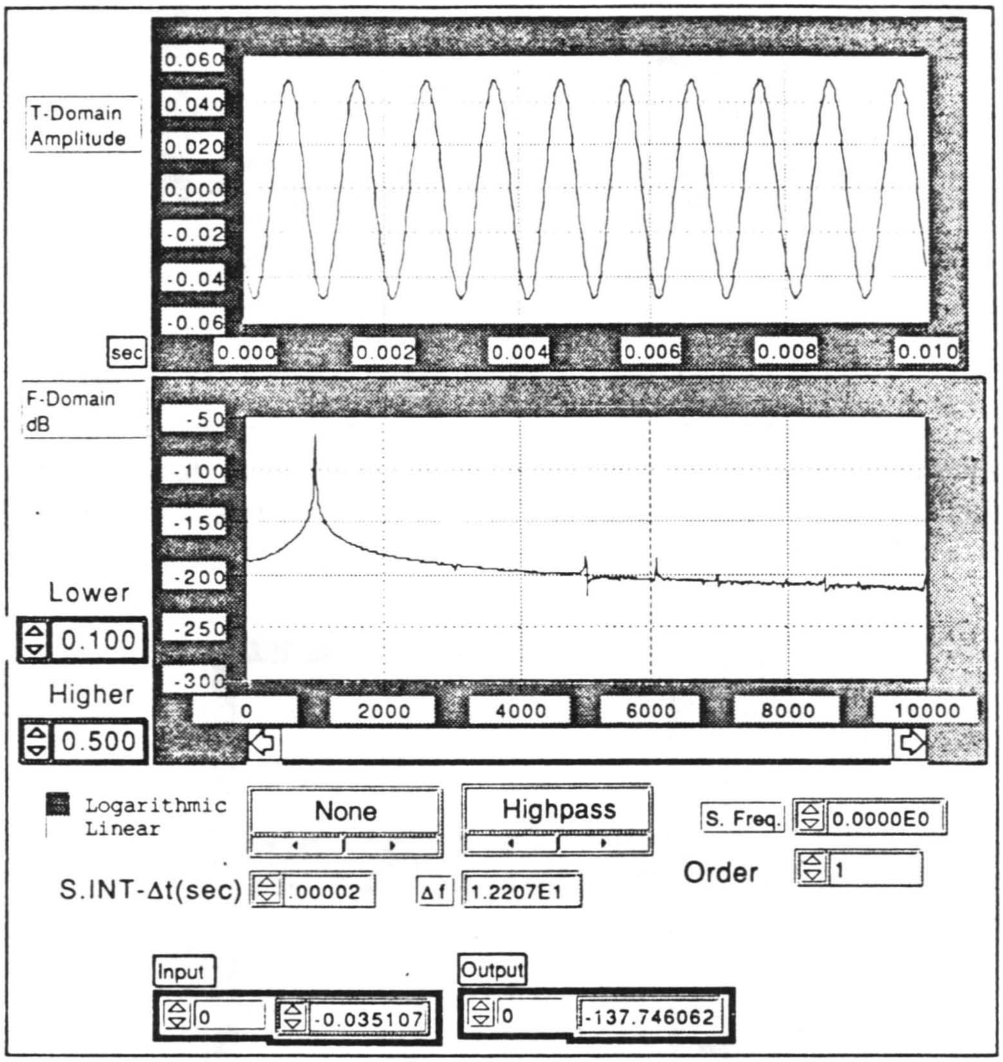


Lower 0.100

Higher 0.500

■ Logarithmic
Linear

None

Highpass

S. Freq. 0.0000E0

Order 1

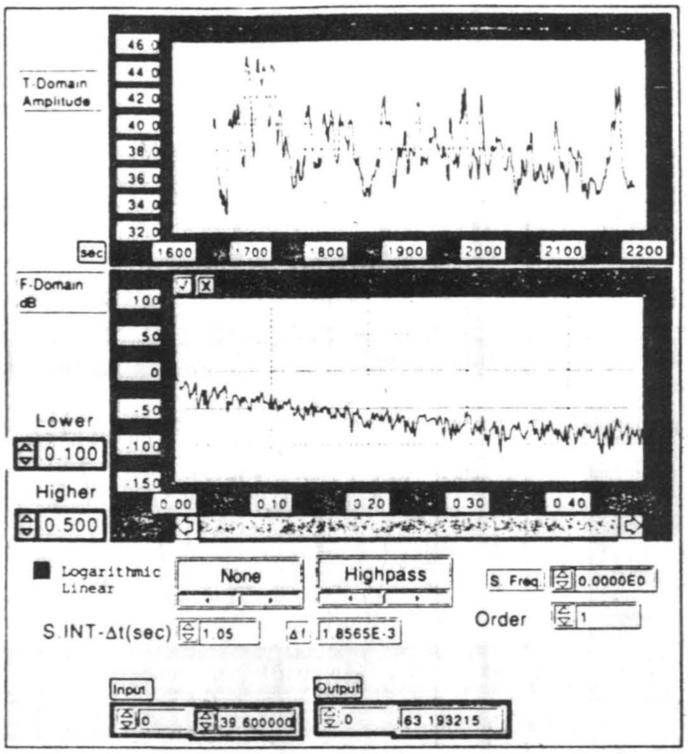
S.INT-Δt(sec) .00002

Δf 1.2207E1

Input 0 -0.035107

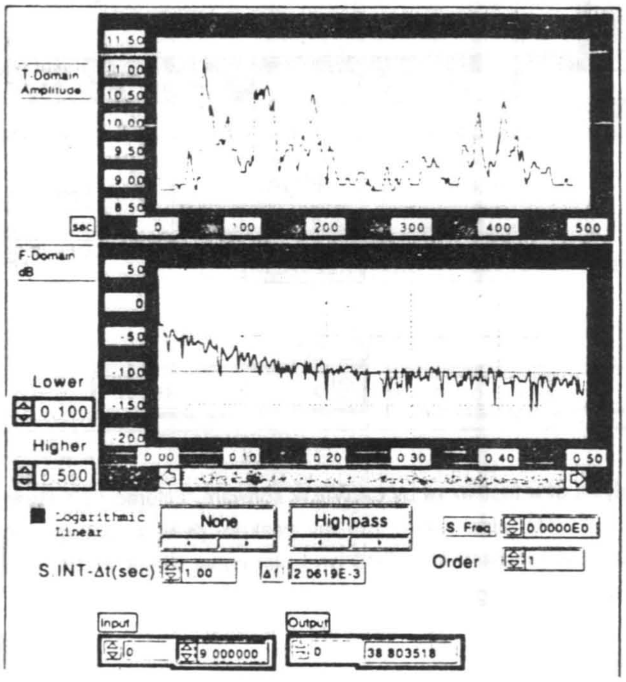
Output 0 -137.746062

Figure 4. Analysis of a test wave by LabVIEW software "Filtered FFT Read" developed for this study: 1000 Hz. sine wave, 100 mv peak-to- peak amplitude, 4096 samples, 20 microsec. sampling increments; PSD on lower curve shows main frequency peak of 1000 Hz., using no filtering.



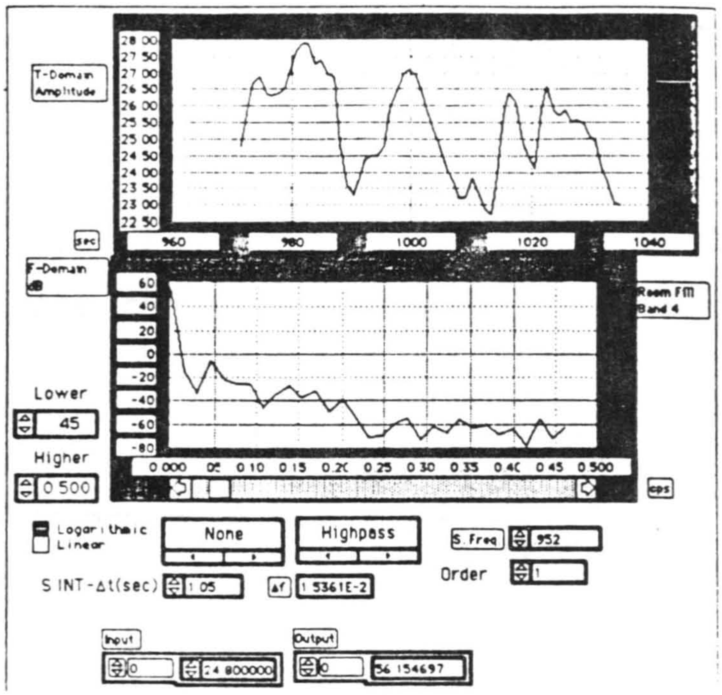
Lower 0.100
Higher 0.500
■ Logarithmic
Linear
None
Highpass
S. Freq. 0.0000E0
Order 1
S.INT-Δt(sec) 1.05
Δf 1.8565E-3
Input 0 39.600000
Output 0 63.193215

Figure 5. Example of HGD Lab helium test data, "BLDG FILL" band 3, spectral analysis using LabVIEW software; data were stored originally at 1.05-sec. intervals, and presently analyzed at this same sample frequency, with no filtering.



Lower 0.100
Higher 0.500
■ Logarithmic
Linear
None
Highpass
S. Freq. 0.0000E0
Order 1
S.INT-Δt(sec) 1.00
Δf 2.0619E-3
Input 0 9.000000
Output 0 38.803518

Figure 6. Example of HGD Lab test data "BLDG FILL", band 1, spectral analysis for 1.0-sec. sample frequency, with no filtering



Lower 45

Higher 0 500

■ Logarithmic
☐ Linear

None

Highpass

S. Freq 952

Order 1

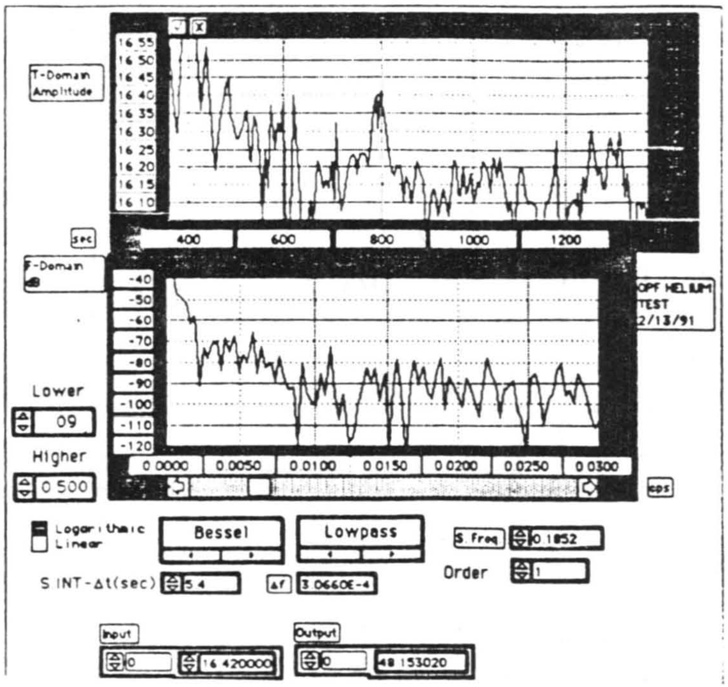
S INT-Δt(sec) 1 05

Δf 1 5361E-2

Input 0 24 800000

Output 0 56 154697

Figure 7. Example of HGD Lab test data "ROOM FILL", band 4, spectral analysis for 1.05-sec. sample frequency, with no filtering



Lower 09

Higher 0 500

■ Logarithmic
☐ Linear

Bessel

Lowpass

S. Freq 0.1852

Order 1

S INT-Δt(sec) 5.4

Δf 3 0660E-4

Input 0 16 420000

Output 0 48 153020

Figure 8. Example of OPF test data spectral analysis for 5.4-sec. sample frequency, with Bessel lowpass filtering

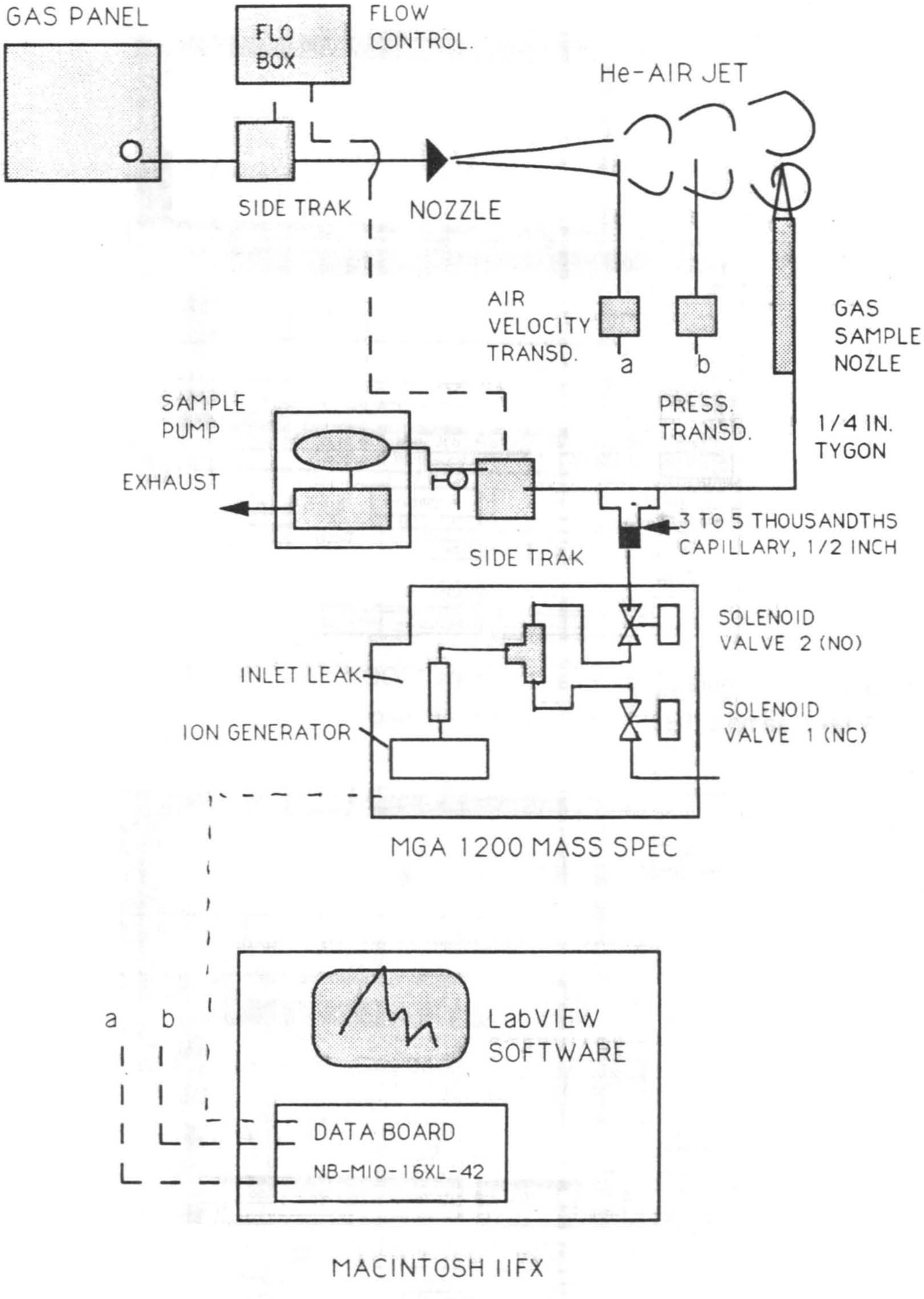


Figure 9. Present experimental setup featuring 1/4-in., 7.5-ft. sample tube and 1/2 in long capillary leak tube

Super Spectrum Analyzerw/o
Wednesday, August 7, 1991 12:54 PM

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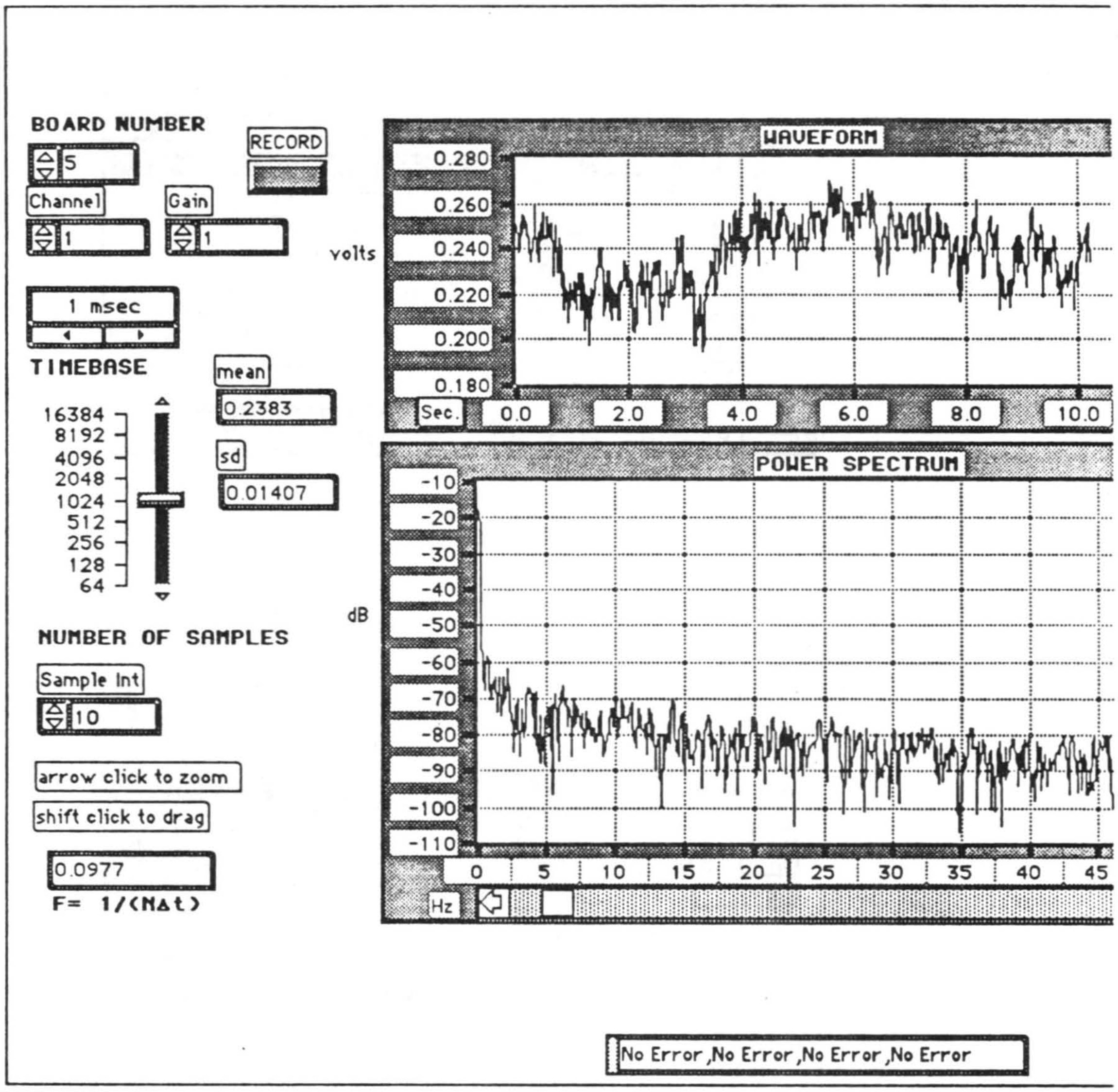


BOARD NUMBER: 5

Channel: 1

Gain: 1

TIMEBASE: 1 msec

mean: 0.2383

sd: 0.01407

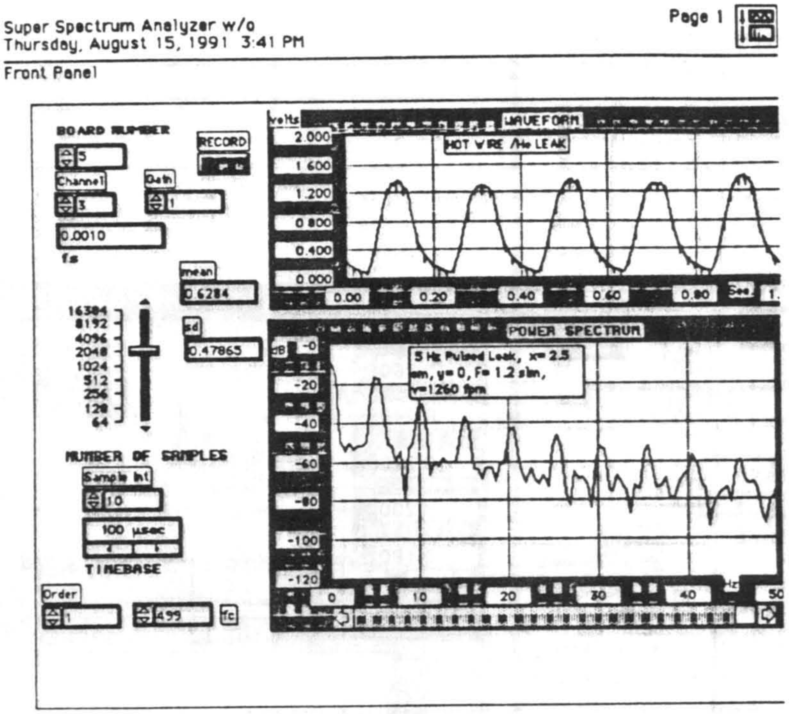
NUMBER OF SAMPLES

Sample Int: 10

0.0977
F= 1/(NΔt)

No Error,No Error,No Error,No Error

Figure 10. Air velocity transducer response to a 2.9 SLM steady helium jet with probe at x = 8 cm., y = 0; local velocity is 692 FPM; initial jet velocity is 760 FPM.



Super Spectrum Analyzer w/o
Thursday, August 15, 1991 3:41 PM

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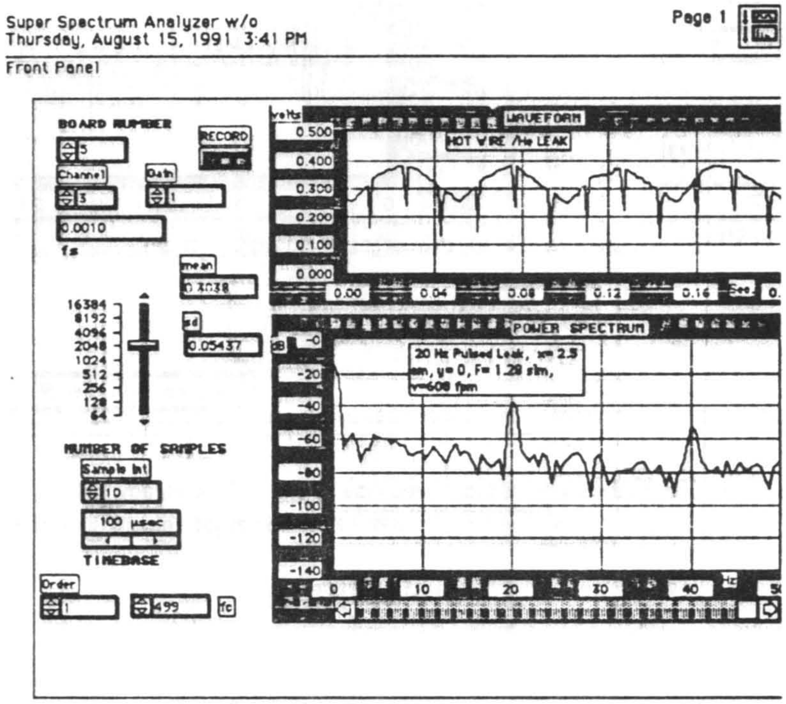
Front Panel

BOARD NUMBER: 5
Channel: 3
Gain: 1
fs: 0.0010
mean: 0.6284
sd: 0.47865
NUMBER OF SAMPLES
Sample Int: 10
TIMEBASE: 100 µsec
Order: 1
fc: 499

5 Hz Pulsed Leak, x= 2.5 cm, y= 0, F= 1.2 slm, v=1260 fpm



Super Spectrum Analyzer w/o
Thursday, August 15, 1991 3:41 PM

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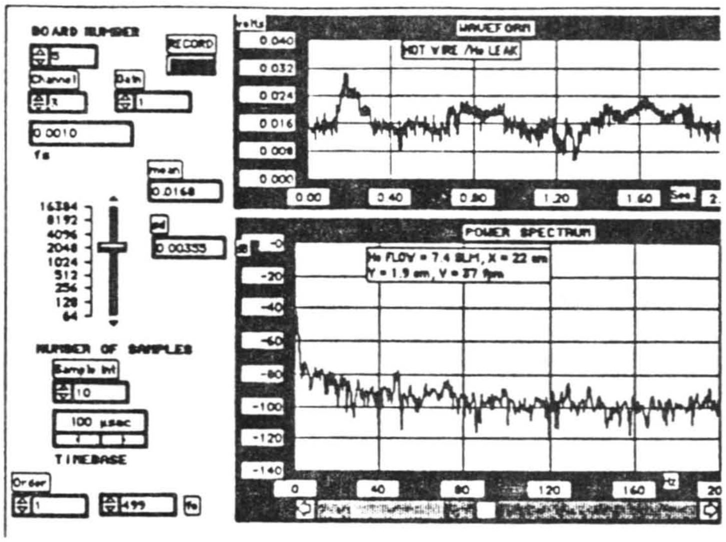
Front Panel

BOARD NUMBER: 5
Channel: 3
Gain: 1
fs: 0.0010
mean: 0.3038
sd: 0.05437
NUMBER OF SAMPLES
Sample Int: 10
TIMEBASE: 100 µsec
Order: 1
fc: 499

20 Hz Pulsed Leak, x= 2.5 cm, y= 0, F= 1.28 slm, v=608 fpm

Figure 11. Response of air velocity transducer to pulsed helium jet; probe at 2.5 cm downstream in centerline. Top: 5 Hz, helium flow at 1.24 SLM, local velocity at 1260 FPM; bottom: 20 Hz, helium flow at 1.28 SLM, local velocity at 608 FPM



BOARD NUMBER 5

Channel 2

Gain 1

fs 0.0010

mean 0.0168

sd 0.00355

NUMBER OF SAMPLES 2048

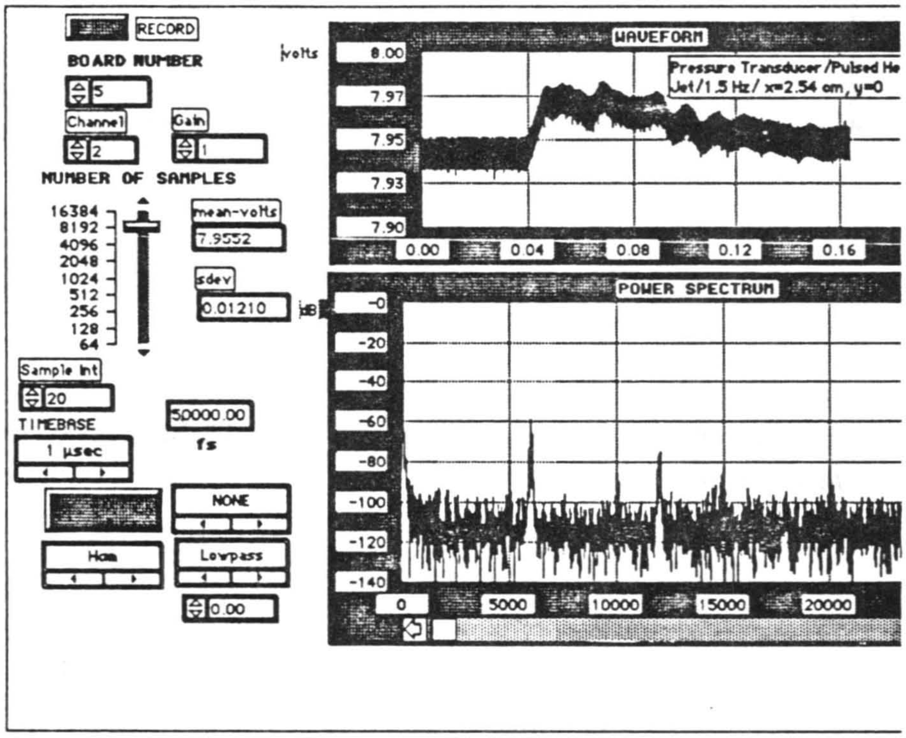
Sample Int 10

TIMEBASE 100 µsec

Order 1

499

Figure 12. Air velocity transducer in helium jet flowing into room air; probe at 22 cm downstream offset from centerline (x = 22, y = 1.9 cm.). Helium flow is 7.4 SLM, local velocity is 37 FPM, initial jet is 1930 FPM.



BOARD NUMBER 5

Channel 2

Gain 1

NUMBER OF SAMPLES 16384

mean-volts 7.9552

sdev 0.01210

Sample Int 20

TIMEBASE 1 µsec

fs 50000.00

NONE

Ham

Lowpass

0.00

Figure 13. High frequency response of the Rosemount pressure transducer to a 1.5 cycle pulsed helium jet

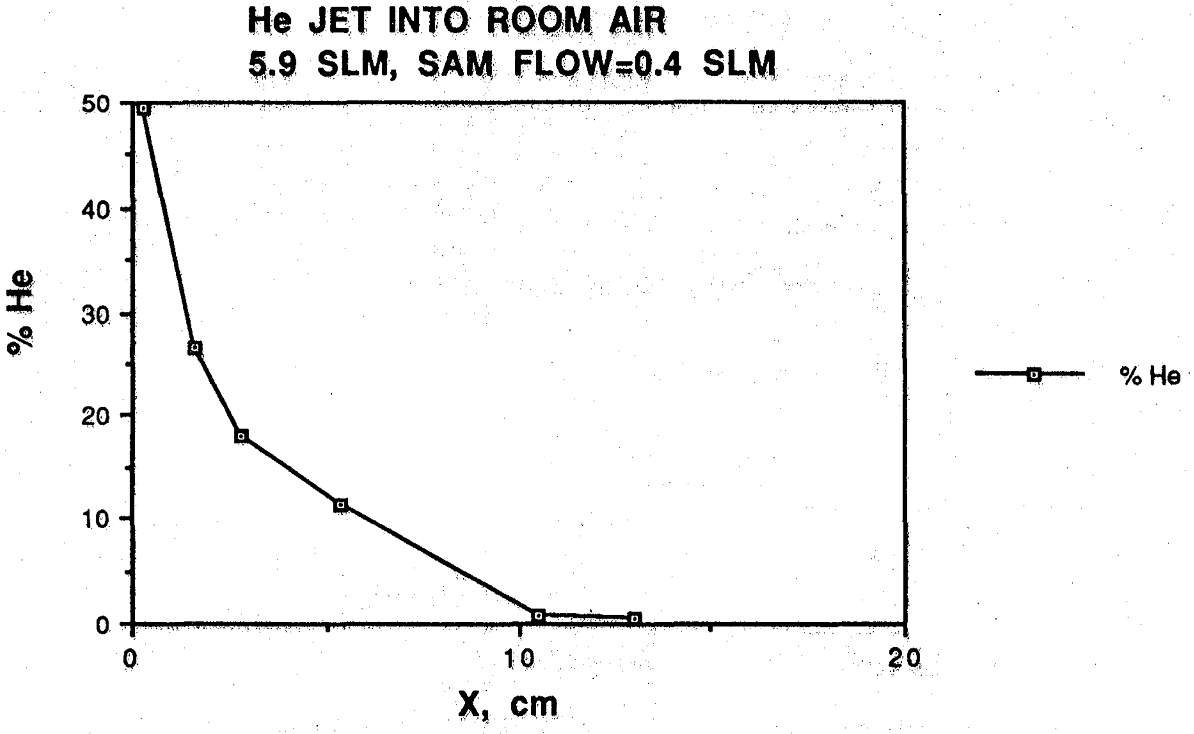
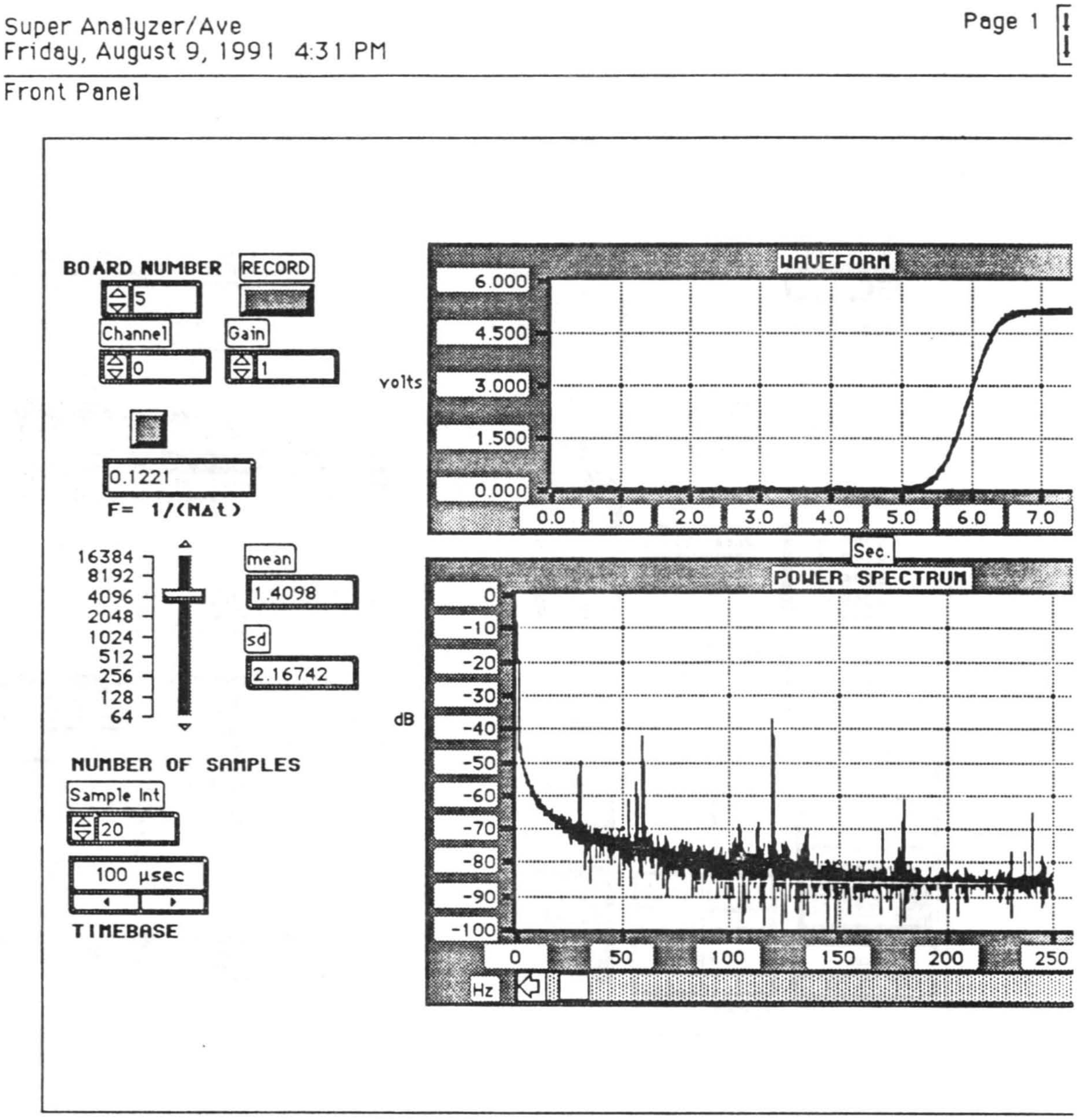


Figure 14. Helium concentration decay in a steady jet of 5.9 SLM using time-averaged data with 1/4-in., 7.5-ft. sample tube



Super Analyzer/Ave
Friday, August 9, 1991 4:31 PM
Page 1

Front Panel

BOARD NUMBER: 5

Channel: 0

Gain: 1

0.1221

F= 1/(NΔt)

mean: 1.4098

sd: 2.16742

NUMBER OF SAMPLES: 4096

Sample Int: 20

TIMEBASE: 100 µsec

Figure 15. Response of 1/4-in., 7.5-ft. sample tube and MGA-1200 to a step input of helium

Ultra Spectrum Analyzer w/o
Tuesday, August 20, 1991 9:18 AM

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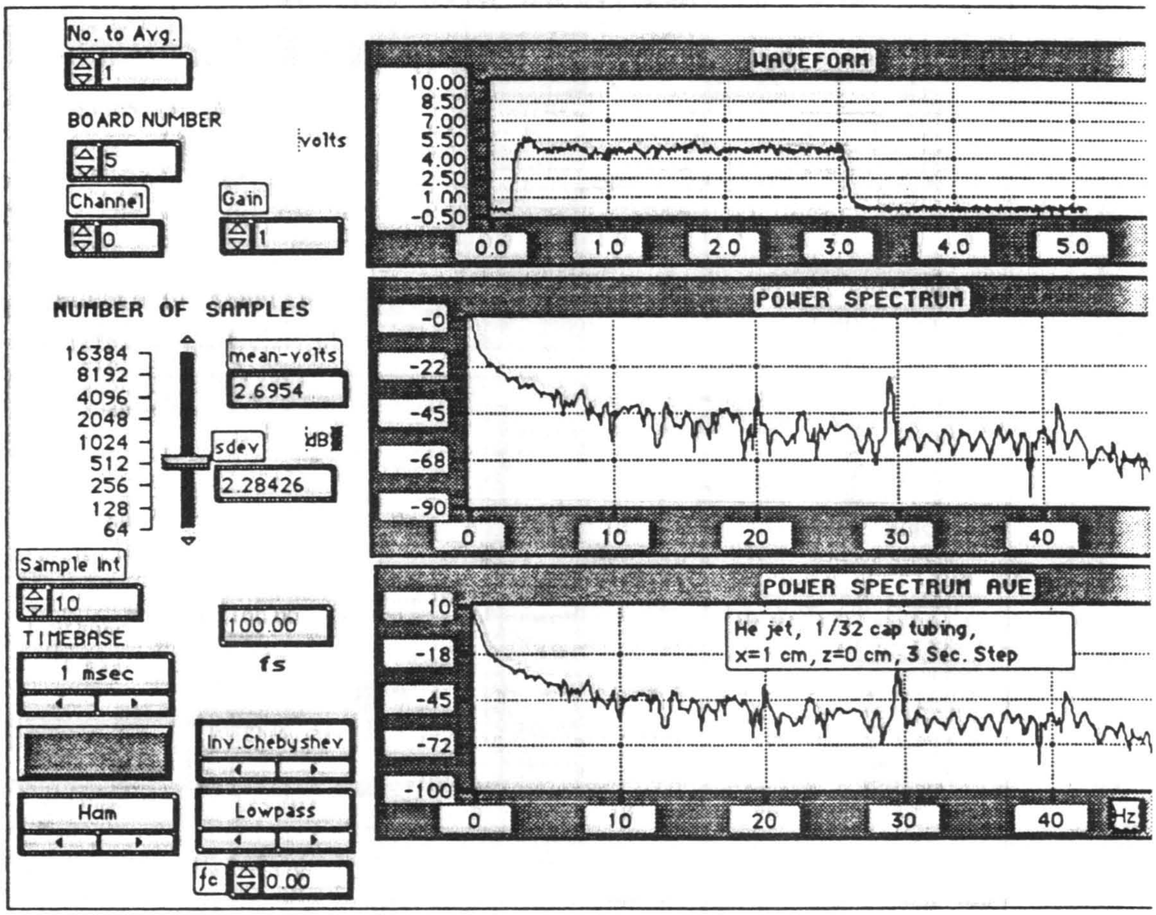
Front Panel



No. to Avg.: 1

BOARD NUMBER: 5

Channel: 0

Gain: 1

mean-volts: 2.6954

sdev: 2.28426

Sample Int: 10

TIMEBASE: 1 msec

fs: 100.00

Ham

Inv.Chebyshev

Lowpass

fc: 0.00

He jet, 1/32 cap tubing,
x=1 cm, z=0 cm, 3 Sec. Step

Figure 16. Response of 1/32-in., 15-ft. sample tube and MGA-1200 to a square wave input of helium