NASA-TM-112637

Sample Delivery and Computer Control Systems for Detecting Leaks in the Main Engines of the Space Shuttle

*Timothy P. Griffin, Guy R. Naylor, Richard J. Hritz
I-Net, Inc., Kennedy Space Center, FL 32899
(407)867-6755
Carolyn A. Barrett
NASA, Kennedy Space Center, FL 32899

Introduction

The main engines of the Space Shuttle use hydrogen and oxygen as the fuel and oxidant. The explosive and fire hazards associated with these two components pose a serious danger to personnel and equipment. Therefore prior to use the main engines under go extensive leak tests. Instead of using hazardous gases these tests utilize helium as the tracer element. This results in a need to monitor helium in the ppm level continuously for hours. The major challenge in developing such a low level gas monitor is the sample delivery system. This poster discuss a system developed to meet the requirements while also being mobile. Also shown is the calibration technique, stability, and accuracy results for the system.

Background

From the beginning of the Space Shuttle program mass spectrometers have been used to monitor for cryogenic fuel leaks. However, there was not a dedicated system to look for leaks of the engines prior cryogenic filling of the Space Shuttle. The major limitation with these systems was that only the cryogenic fuels could be monitored (i.e., Hydrogen and Oxygen) unless the vacuum system was broken to replace the vacuum pump. This limitation was due to the ion pumps that were used in the vacuum systems. Even with this limitation leaks were found multiple times. However, as discovered in the summer 1989, these systems were of limited use when trouble shooting the locate of the leaks.

Shuttle missions STS-35 and 38 were grounded during the summer of 1989 due to hydrogen leaks in the Aft Fuselage and the 17" disconnect. These leaks grounded the shuttles all summer at a great cost in both money and time. This was highlighted (Picture 1) when the Space Shuttle Columbia (mission STS-35) rolled back to the Vehicle Assembly Building (VAB) to repair the leaks. Because the leaks were not detected until the Space Shuttles were on the pad they had to be rolled back to the Vehicle Assembly Building. While the existing systems detected the hydrogen leaks they were not able to adequately trouble shoot the problem. The ion pump systems of the older mass spectrometers could not adequately handle the high helium loads. For this reason, a turbo pumped mass spectrometer system was designed. This system, named Hydrogen Umbilical Mass Spectrometer (HUMS), was successful in helping to resolve the leaks in the Orbiters.

These problems brought out the need for improved methods to look for leaks before and after installing the main engines into the Orbiter. The requirements of the system included the ability to move the system to different locations with minimal effort. The system was to be used for refurbishment of the engines prior to installation into the Orbiter and to test the overall Space Shuttle once on the launch pad. The Portable Aft Mass Spectrometer (PAMS) was developed to meet these requirements.

Experimental

The PAMS system (Picture 2)was composed of three sections, the sample delivery system, the mass spectrometer, and the interface software. The sample delivery system (SDS), on the back of the cart, used a flow controller and pressure transducer to control the inlet pressure of the mass spectrometer. The mass spectrometer, on the bottom of the cart (Picture 2), was a fixed sector with a turbo molecular drag pump. The control software was written in LabView and runs on a laptop personal computer (PC) located on a pull out shelf (Picture 2).

Sample Delivery System

The pneumatic schematic for the SDS is shown in Figure 1. The system has two inlet ports, three on board calibration gases, a pressure transducer, and a flow controller. The heart of the system is the control loop which keeps a constant pressure at the inlet of the mass spectrometer. This is accomplished by monitoring the pressure via a pressure transducer (PT on Figure 1). The flow controller (FC on Figure 1) then adjusts the sample flow to maintain a constant pressure at the inlet of the mass spectrometer. This control loop is constantly monitored while the system is operating. To calibrate the mass spectrometer, two on board calibration gases (Span and Zero) and one accuracy checking gas (Test) are incorporated into the system; they also are controlled to the same inlet pressure as the sample. There are two inlets into the SDS. One inlet is for high flow rates (~8 L/min) while the second is for low flow rates (~0.5 L/min). A dual diaphragm pump is used to enable the two inlet flow rates.

Mass Spectrometer

The mass spectrometer used for the PAMS unit is the Alcatel 120 h helium leak detector. The unit is a magnetic sector with dual Faraday cups to allow a wide dynamic range of the mass spectrometer. Sample introduction was accomplished by passing the sample across a membrane into the mid body of the turbo molecular drag pump. This technique of contra flow has been shown to allow lower limits of detection than introduction into the base of the drag pump.

Control Software

The interface software, written in LabView 4.0.1, controlled and monitored the SDS and mass spectrometer. The SDS line selection valves were controlled via Analog Devices solid state relays (OD60Q). The Alcatel mass spectrometer was designed as a leak detector and therefore only supplies voltages corresponding to leak rates. For this reason, the Faraday cups on the mass spectrometer were interfaced to the computer by Analog Device's 6B12 input modules. The pressure and flow were monitored by the MKS Control System Type 146. All components (i.e., MKS, Analog Devices, Alcatel) communicated directly with the control lap top computer via serial ports.

The main screen of the software, Figure 2, has four areas. The first section (top two data graphs) display the data both graphically, as a trend, and numerically. The second section is on the lower left of the screen and consists of the labeled areas Line Select, Sample Flow, Transport Flow, and System. This section allows the user to control, monitor, and validate the SDS and mass spectrometer. The third section, labeled Pages, consists of the tests performed to check out the Space Shuttle prior to launch. The fourth section is on the lower right and has the labels File Control and Time. This section lets the user select the data file and the delay between scans.

System Evaluation

Three tests were run to evaluate the overall performance of the PAMS. These tests were calibration, accuracy, and long term drift. The calibration gases and experimental parameters are summarized in Table 1.

Calibration

The calibration of the unit was performed as explained below. Each of the calibration gases were monitored for a set time, in the order zero, test, and span. This sequence was chosen to help reduce memory effects. The data acquired during the last five minutes of each gas were then averaged together. The first five to ten minutes were used to allow stabilization of the system. Linear regression was then performed on the zero and span gases. The concentration of the test gas was then calculated using the slope and intercept. This calculated value was then compared to the actual value of the test gas to check the calibration of the unit.

Accuracy

The same method to determine the test gas values in Calibration above were used to determine the accuracy of the unit. Two gas concentrations, low (~11 ppm) and high (~103 ppm), were obtained from the Bureau of Mines.

These values were chosen because they were close to the lower and upper range of the instrument during normal operation (i.e., low range on the Alcatel).

Long Term Drift

To test the extent that the unit drifts two gases were monitored for 90 min each. The two gases were the 50 ppm test gas and the 0 ppm zero gas. These two gases were chosen because the low level drift is of a major concern during operation of the unit. Furthermore the base line drift was able to be observed using the zero gas.

Table 1. Experimental Parameters

Gases (all are He in N2 background):

Calibration:
Span: 100 ppm
Test: 50 ppm
Zero: 0 ppm
Accuracy Study:
Low range: 11.2 ± 0.015 ppm
High range: 103.95 ± 0.55
Long term drift Study:
50 ppm

Inlet Pressure: 700 Torr
Sample Flow Rate: 0.5 L/min

Results and Discussion

Calibration:

The voltages acquired for calibration are shown in Figure 3. Table 2 lists the averages and standard deviation of the last five minutes for each of the calibration gases (Average and Std Deviation), the linear regression data (Slope and intercept), the calculated concentration of the test gas (Calc ppm), the deviation of the calculated test gas concentration from the actual (Delta from actual), and the percent error (% Error) of the Delta from actual. To graphically demonstrate this calibration technique the span and test gas data were plotted (Figure 4). The solid black line in the figure is the linear regression line used for calibration. The blue dotted line shows the check of the calibration line by using the calibration voltage to calculate the test gas concentration. As these data show the calibration routines are very accurate and the response of the system is very linear with small standard deviations.

Table 2. Calibration results for PAMS

	0 ppm	50 ppm	100 ppm
Average	-0.00615	-2.308	-4.626
Std Deviation	4.1x10-5	2.57x10-3	1.12x10-2
Linear Regression:			
Slope	-21.64		
Intercept	-0.131		
Test Gas Results :			
Calculated ppm	50.18		
Delta from actual	0.18		
% Error	0.37		

Accuracy

As can be seen in Table 3 the accuracy of the system is extremely good. The 11.2 ppm calculated average was equal to the actual value of the gas. The standard deviation also was found to be less the 1% of the concentration. Although the 103.95 ppm gas measured a value of 98.5 ppm the percent error was still less then 10% and adequately meets the systems needs. This error can be attributed to the fact that this concentration is at the high end for the low-range Faraday cup on the mass spectrometer. Therefore larger errors will be seen above 100 ppm unless the system is calibrated with the high range Faraday cup. This is acceptable, as low level accuracy is of extreme importance.

Table 3. PAMS Accuracy Results.

Actual (ppm)	Calc (ppm)	Std Dev	Delta (ppm)	% Error
11.2 ± 0.015	11.2	0.02	0.0	0.42
103.95 ± 0.55	98.2	0.15	-5.8	5.5

Long Term Drift

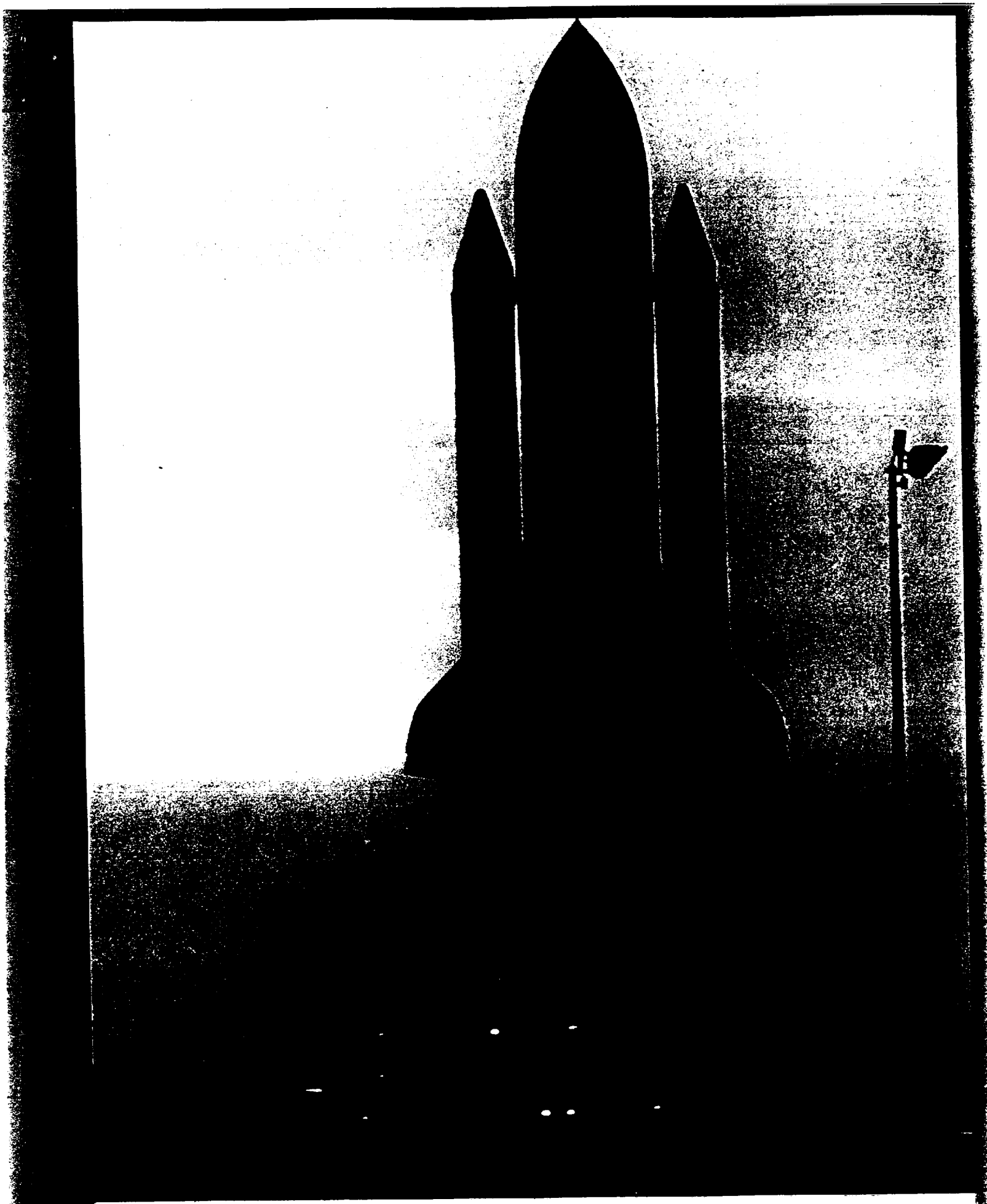
The results for monitoring zero and test gases for 90 min (Figure 5) shows a very stable response. The standard deviation in both cases were extremely small and the drift was less then 0.5 ppm. The small rise in the 50 ppm signal during the first 40 min of the run can be attributed to stabilization of the SDS and mass spectrometer systems.

Conclusion

A portable mass spectrometer system has been successfully developed and used to monitor helium levels in the Space Shuttle prior to launch. The system showed exceptional linearity, accuracy, and long term stability. The system has been successfully used on a number of launches. Although the current system was limited to monitoring helium, the addition of a scanning mass spectrometer would make this system applicable for many long term process monitoring applications. The size of the sample delivery system would enable the unit to be permanently installed into small areas. The control of the system could be automated (i.e., when to calibrate or cycle valves). This automation would make the system suitable for autonomous operation.

Acknowledgements

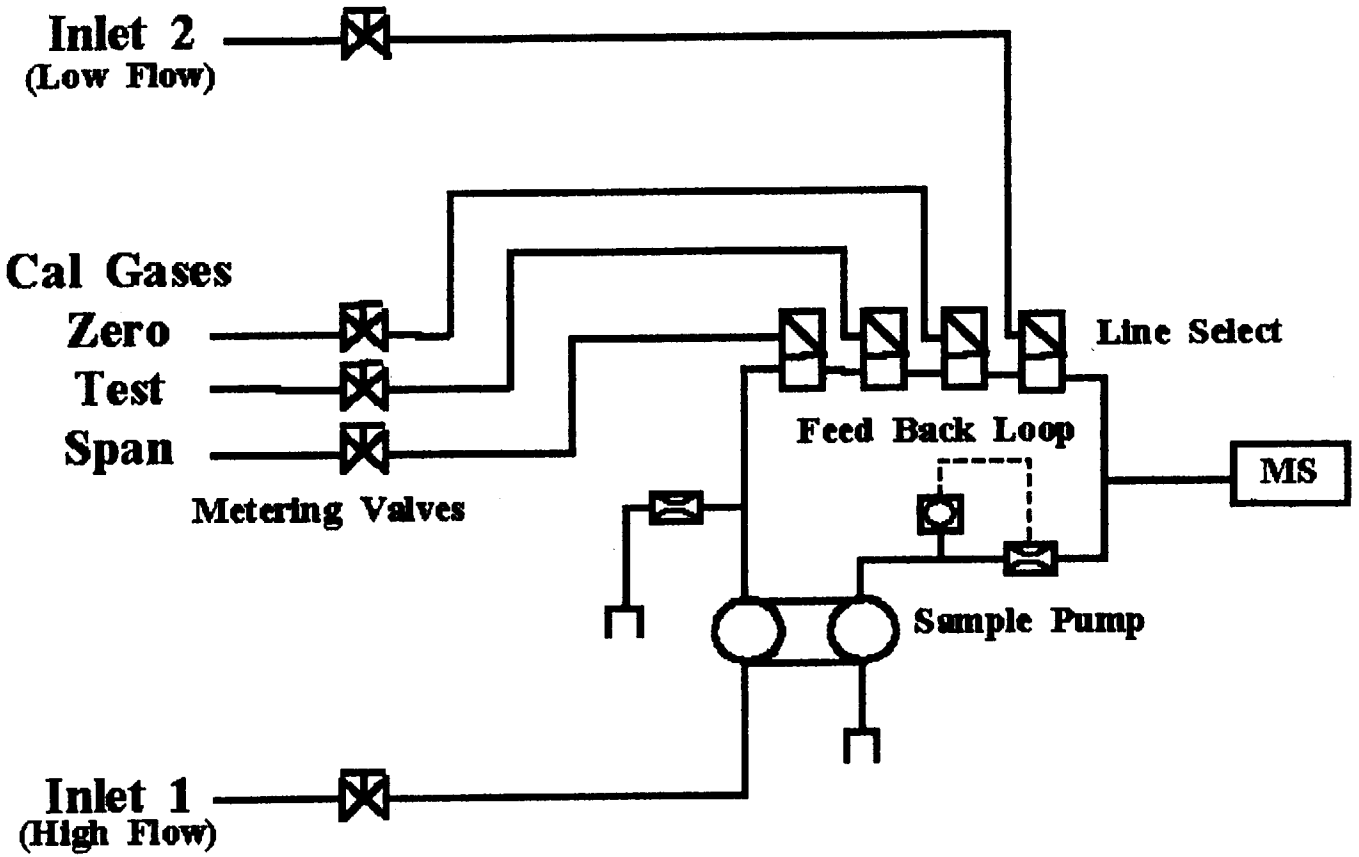
The authors would like to acknowledge the NASA Hazardous Warning Department for funding of the project. Special thanks go to Richard Mizel, Gregg Bresnik and Miguel Fernadez for their feed back on the operation of the system.



Picture 1. Columbia Rolling Back to the VAB

Picture 2. PAMS System

Figure 1. Pneumatic Schematic of PAMS



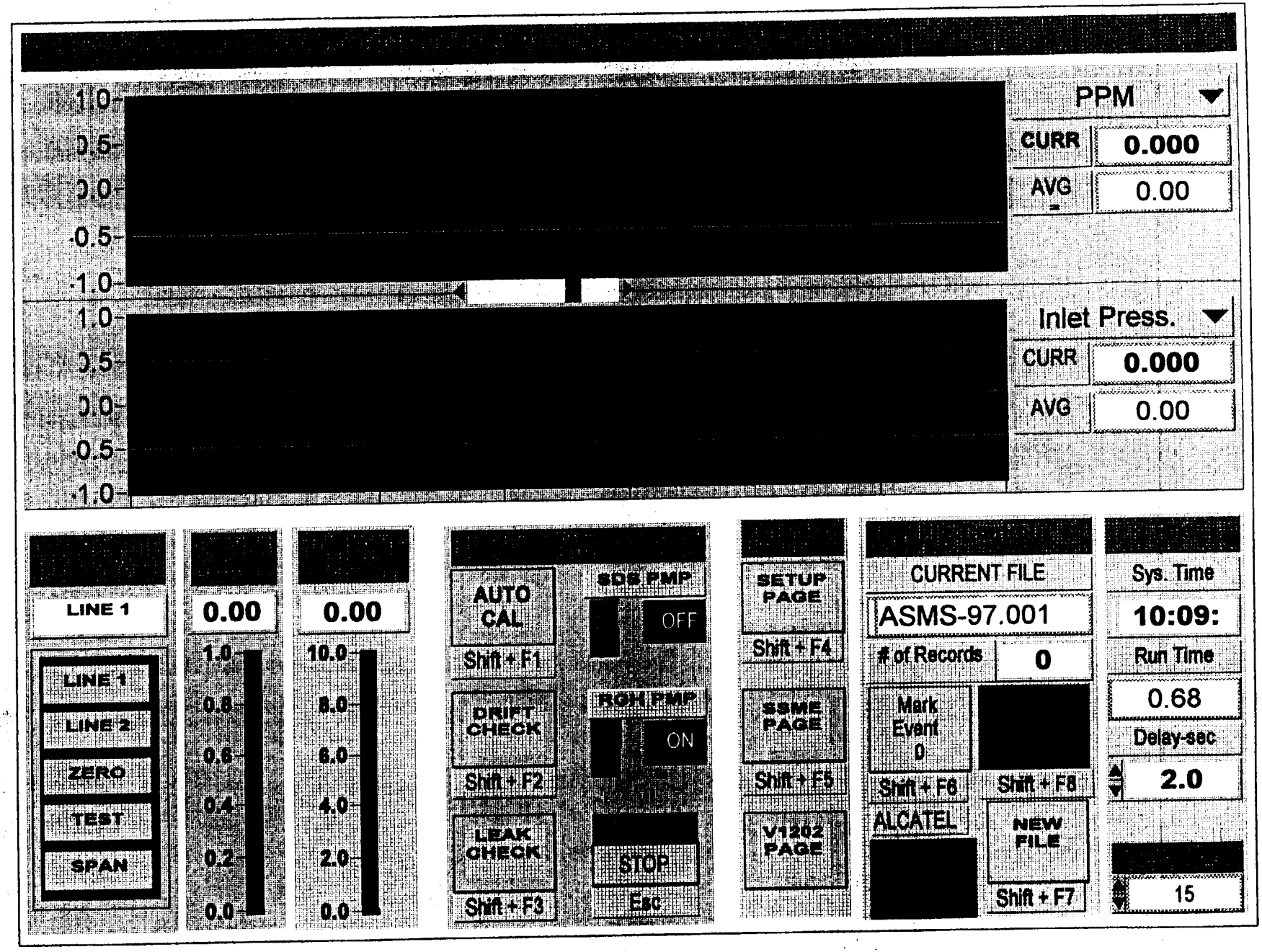


Figure 2. PAMS Control Software

Figure 3. Mass Spectrometer Response
Helium Calibration, N_2 Background
Inlet: 700 Torr, 500 sccm

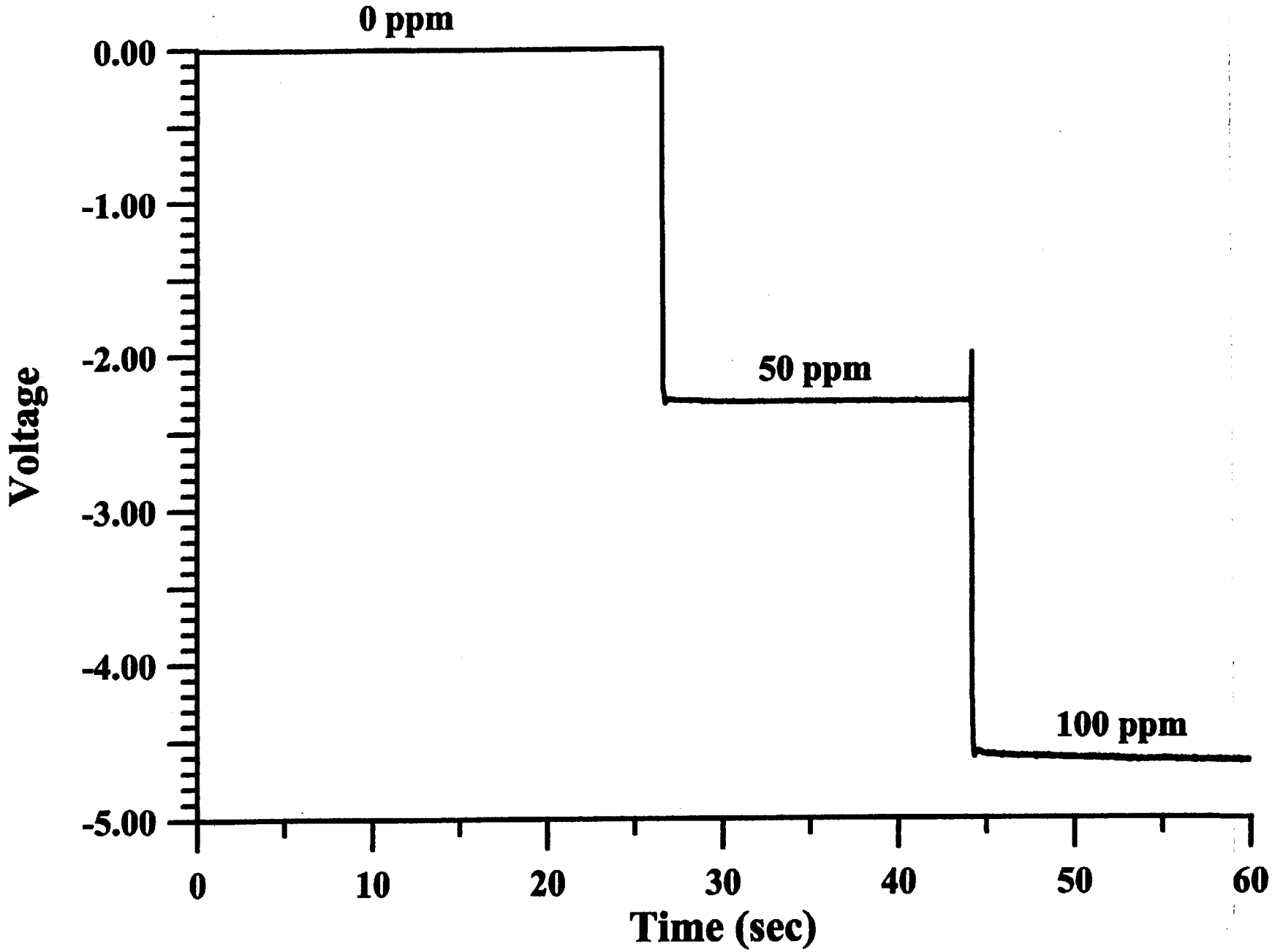


Figure 4. Calibration Curve
Including Test Results of 50 ppm Helium
N_2 Background
Inlet: 700 Torr, 500 sccm

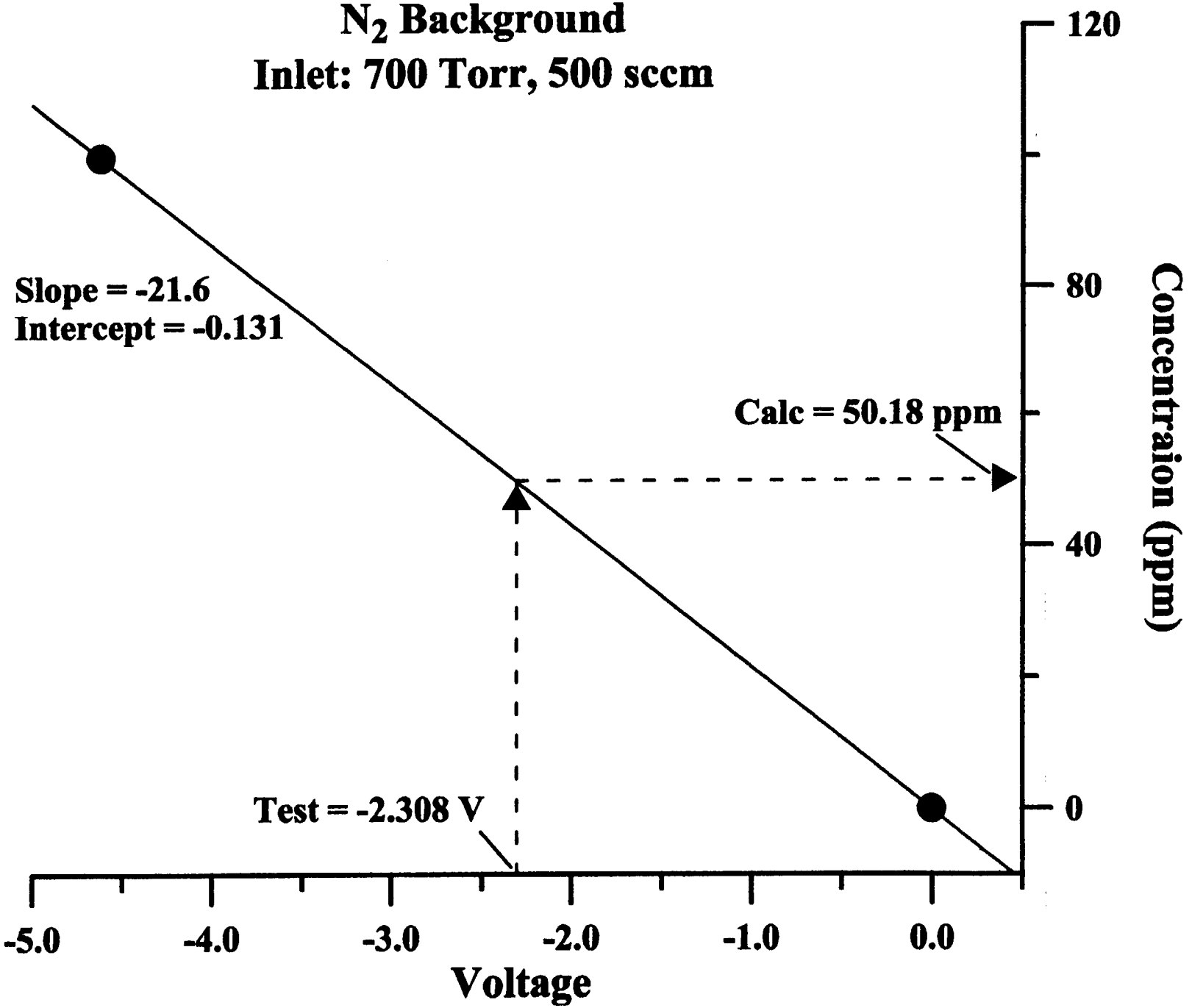


Figure 5. Helium Drift Data
N_2 Background
Inlet: 700 Torr, 500 sccm