D47

N85-16936

HISTORY, DESIGN AND PERFORMANCE OF THE SPACE SHUTTLE HAZARDOUS GAS DETECTION SYSTEM

William R. Helms
NASA, Engineering Development Directorate
John F. Kennedy Space Center, Florida 32899

ABSTRACT

Large quantities of hazardous cryogenic propellants are loaded aboard the Space Shuttle prior to launch. The Hazardous Gas Detection System is designed to detect leaks which could result in pre-launch or in-flight fires or explosions.

This paper describes the historical development, design, and performance of the HGDS. Data for response time, detection limits, accuracy, and drift are presented. Finally, present and future applications are discussed, and some general conclusions are drawn.

INTRODUCTION

Over 1.5 million pounds of liquid oxygen and liquid hydrogen are pumped onto the Space Shuttle during final countdown. Leaks, either during pre-flight preparations, or in-flight could result in a fire or explosion which would endanger the Space Shuttle and its crew. The Hazardous Gas Detection System (HGDS) is designed to detect the presence and measure the concentration of hazardous gases within the Space Shuttle.

The HGDS is located inside the Mobile Launch Platform and consists of three subsystems. The sample delivery subsystem draws samples from four Space Shuttle compartments surrounding propellant tanks and engines, and provides calibration gas samples. These compartments are the External Tank Intertank Area, the Orbiter Aft Fuselage, Payload Bay, and Midbody. All are purged with gaseous nitrogen during propellant loading. The mass spectrometer measures the samples from these areas qualitatively and quantitively for specific compounds. These are hydrogen, oxygen, helium, argon, and up to four others. The control and data subsystem controls the entire system, and provides operator interface for local setup via keypads and a display panel. Once this setup is complete, control is transferred to the Firing Room in the Launch Control Center. All measurement and control during propellant loading is handled through the Launch Processing System. The Firing Room console operator controls the system and warns propellant loading and test management personnel of leaks which might endanger the Shuttle or the astronauts.

HISTORY

The Hazardous Gas Detection System was first used in the early Saturn program. A need to detect leaks in the Saturn I Launch Vehicle was recognized in 1964. The first HGDS was a modified magnetic sector residual gas analyzer. It was brought from Huntsville for each launch, set up, and operated by a chemist from Marshall Space Flight Center.[1] As Figure 1 shows, it was crude, and could only measure hydrogen, but it demonstrated the potential of mass spectrometry as applied to space vehicle leak detection.

The system was gradually improved until, by the first Saturn V flight, a stable design configuration was reached. A valve manifold was added to allow sampling from four areas and from a calibration gas cylinder. Packaging was improved and a peak selector was added to allow measurement of hydrogen, oxygen, nitrogen, helium, and argon.[2] The Saturn V configuration is shown in Figure 2.

The Saturn HGDS produced reliable data throughout the program. It never failed to operate when needed; however, it required time consuming maintenance and calibration. The operator interface was anything but simple. System operation was slow, requiring eight minutes to survey the entire space vehicle. For the Space Shuttle program, a faster, more operator-friendly system was needed, while still retaining the sensitivity and flexibility of a mass spectrometer.

SHUTTLE HGDS DESIGN

A set of design goals was established to guide the development of the Shuttle HGDS.
- Fast response (2 minutes to survey the entire Shuttle)
- Accurate (+/-5% of reading)
- Automatic calibration and operation

- Flexible, to meet changing requirements
- Rugged, to meet the launch vibration environment

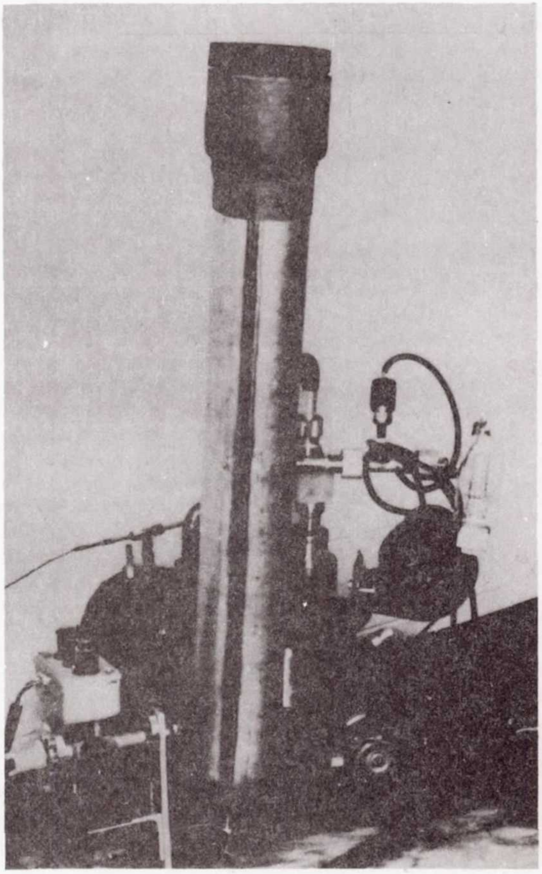

Fig 1.- Saturn I HGDS.

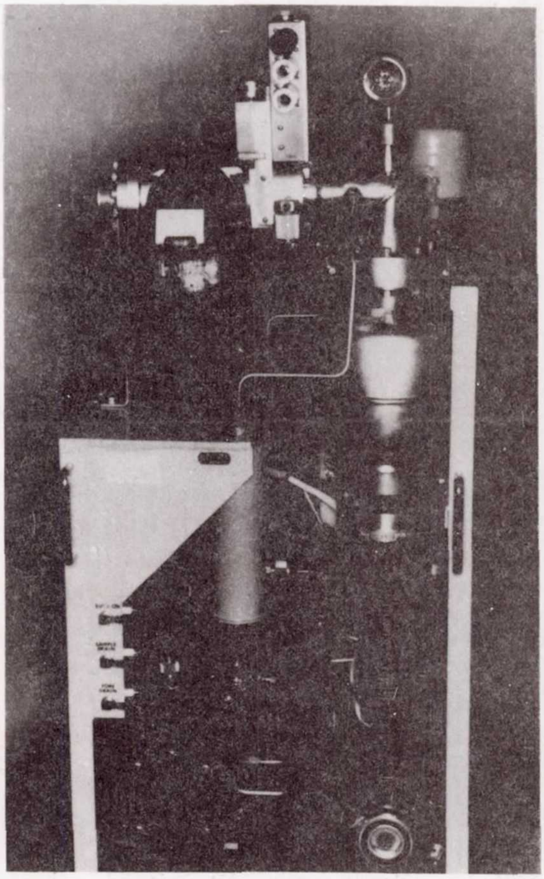

Fig 2.- Saturn V HGDS.

In order to demonstrate these concepts, a prototype system was constructed and tested by the Design Engineering Directorate at Kennedy Space Center. It was sent in 1977 to the National Space Technology Laboratories in Bay St. Louis, MI, for Main Propulsion Test Article static firings. Experience from KSC and MPTA testing was used to formulate the specifications for operational systems.

The prototype HGDS has been described by Helms and Raby.[3] The sample subsystem consists of five sample lines, each continuously pumped, plus zero and span gas. The zero gas is ultrapure nitrogen, and allows measurement and subtraction of background gases within the mass spectrometer. The span gas consists of precisely known amounts of each gas to be measured, to allow generation of calibration (sensitivity) coefficients. The mass spectrometer is a commercial quadrupole type, with automatic pumpdown, shutdown, and bakeout, and a mass range of 0-300 AMU. The digital logic controller is built of individual integrated circuit chips, some 250 in all. The operator selects up to eight gases to be measured, and up to five sample lines to be automatically scanned. The system is capable of performing an automatic self-calibration on operator command. Drift and measurement error over an eight-hour period are typically less than five percent (5%) of the reading. Correlation against simulated leaks is better than 0.99.

The operational Hazardous Gas Detection System for the Shuttle program (shown in Figure 3) was designed and built by UTI Instruments, Inc., Sunnyvale, CA. The first of four units was delivered to NASA/KSC in December, 1979. The design has been described in papers by Bunyard et. al.,[4] and Wells.[5] It consists of the same mass spectrometer used in the prototype, and a similar sampling system. These are depicted in Figure 4. However, the digital logic controller is replaced by three

Zilog Z-80A Microprocessors. One controls the sampling system, one the mass spectrometer, and one acts as overall system controller. All programs are contained in EPROM read-only memory. Extensive health-check instrumentation is included to warn the operator of failures which might invalidate the data. This includes sample selector valve and sample transfer pump failures, analog pressure and flow measurements on both the sample subsystem and the mass spectrometer, and various fault indications on the vacuum system, mass spectrometer, and microprocessors.

The operator interface is extremely user-friendly. Guided by "prompt" messages on the local control panel, the operator enters the mass-to-charge ratio, the measurement range, and the calibration gas concentration for each gas to be measured. The system performs an automatic calibration by locating the mass peaks, and generating background (zero) and sensitivity coefficients for each gas. The operator can check or refresh the calibration at any time.

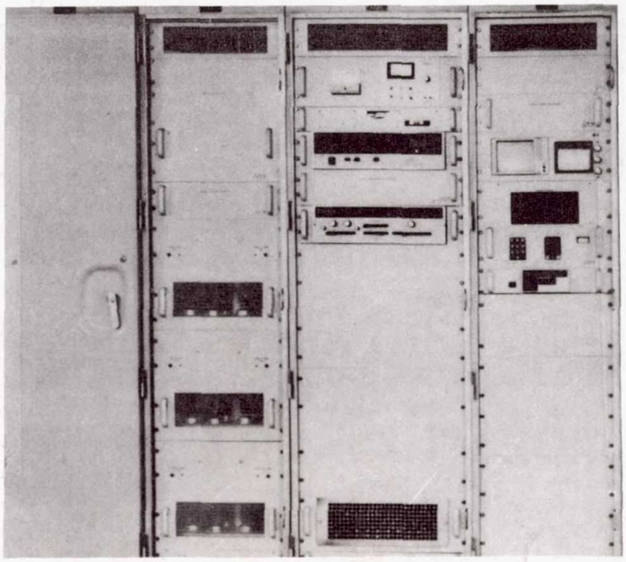

Figure 3.- Space Shuttle HGDS.

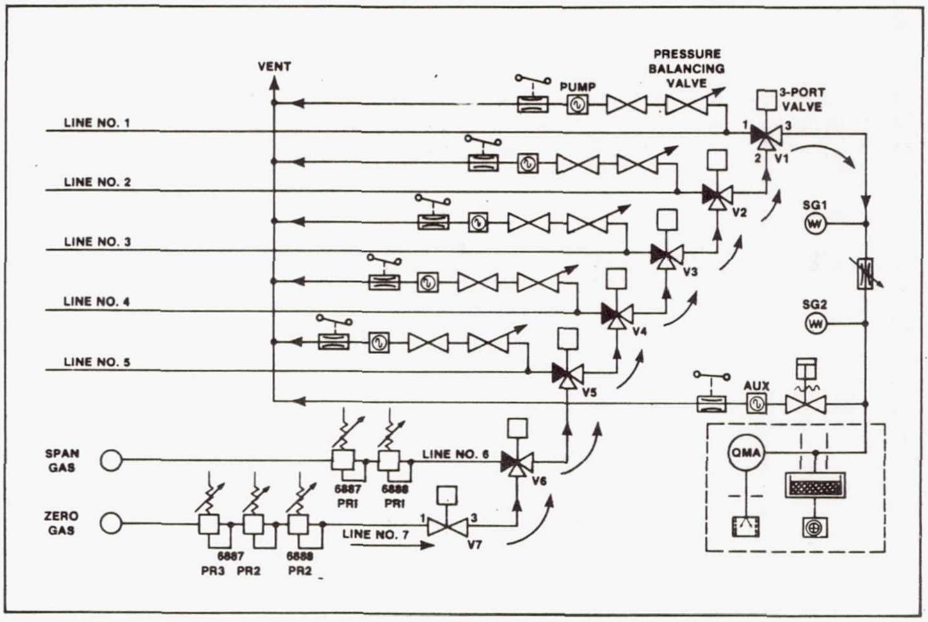

Figure 4.- HGDS schematic.

HGDS PERFORMANCE

Among the most important measures of performance for any analytical instrument are speed of response, detection limit, accuracy, and stability. The HGDS has, in general, met or exceeded its performance design criteria. Initial acceptance tests and periodic performance tests are run to assure optimum performance of the system.

RESPONSE TIME

THE HGDS draws samples from the 200 foot Orbiter sample line in less than twelve seconds, and from the 400 foot External Tank Intertank Area sample line in less than twenty seconds. The design goal was 30 seconds or less. Response at the instrument is virtually instantaneous. The system responds to 50% of a change in concentration in one second, and 90% of a change in two seconds. The HGDS samples up to eight different gases, one each second. In addition, there is a one-time 20 second delay prior to analysis each time a new sample line is selected, to assure adequate purge of the previous sample. With the 20 second delay plus 8 seconds of measurement time for each of four lines, the HGDS can sample all four areas of the Shuttle in 1 minute, 52 seconds, well within the design goal of 2 minutes. Considering a maximum sample transport time of 20 seconds, plus up to eight seconds to analyze all gases, changes in concentration for any one area on the Shuttle can be sampled, analyzed, and reported in 30 seconds or less.

DETECTION LIMITS AND ACCURACY

Detection limits are primarily a function of the precision (repeatability) of a measurement system. A detailed study of both the accuracy and precision of the HGDS was undertaken. Data for hydrogen and oxygen are shown in Table 1 and 2, and in graphical form in Figures 5 and 6. Similar studies, albeit less detailed, were conducted for helium and argon with similar results. From these data, it can be conservatively stated that the HGDS accuracy is +/-5% of the reading or +/-20 ppm, whichever error is greater. Furthermore, using twice the standard deviation as a criterion, the detection limit for hydrogen is 40 ppm, and for oxygen, helium, and argon, less than 10 ppm.

TABLE 1. HGDS ACCURACY AND PRECISION FOR HYDROGEN

Theoretical Concentration	HGDS Reading (Average)	Error (Average)	Standard Deviation	Number of Samples
4040 ppm H_2	3971 ppm	-69 ppm	29 ppm	6
1060 ppm H_2	1037 ppm	-23 ppm	25 ppm	8
491 ppm H_2	511 ppm	+20 ppm	22 ppm	25
250 ppm H_2	258 ppm	+8 ppm	13 ppm	25
100 ppm H_2	96 ppm	-4 ppm	23 ppm	25
50 ppm H_2	55 ppm	+5 ppm	22 ppm	25
24 ppm H_2	27 ppm	+3 ppm	11 ppm	25

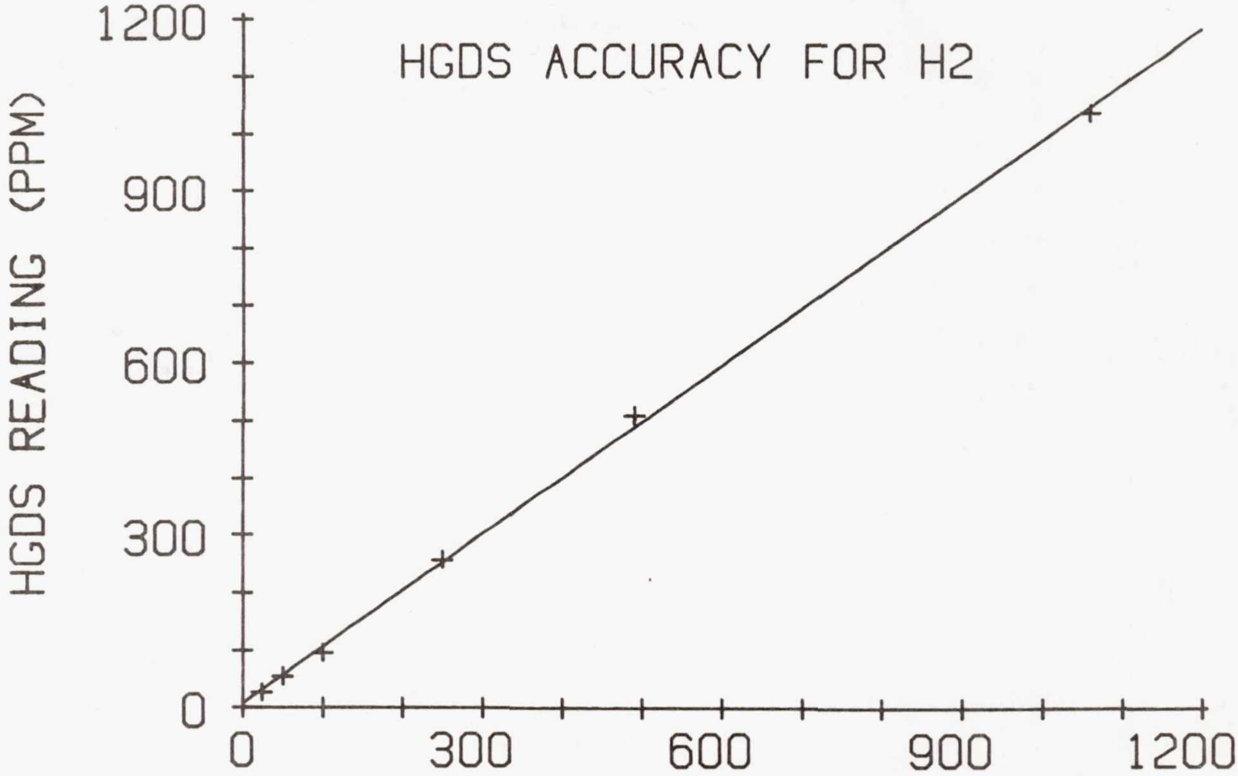

Figure 5.- Input H_2 conc. (PPM).

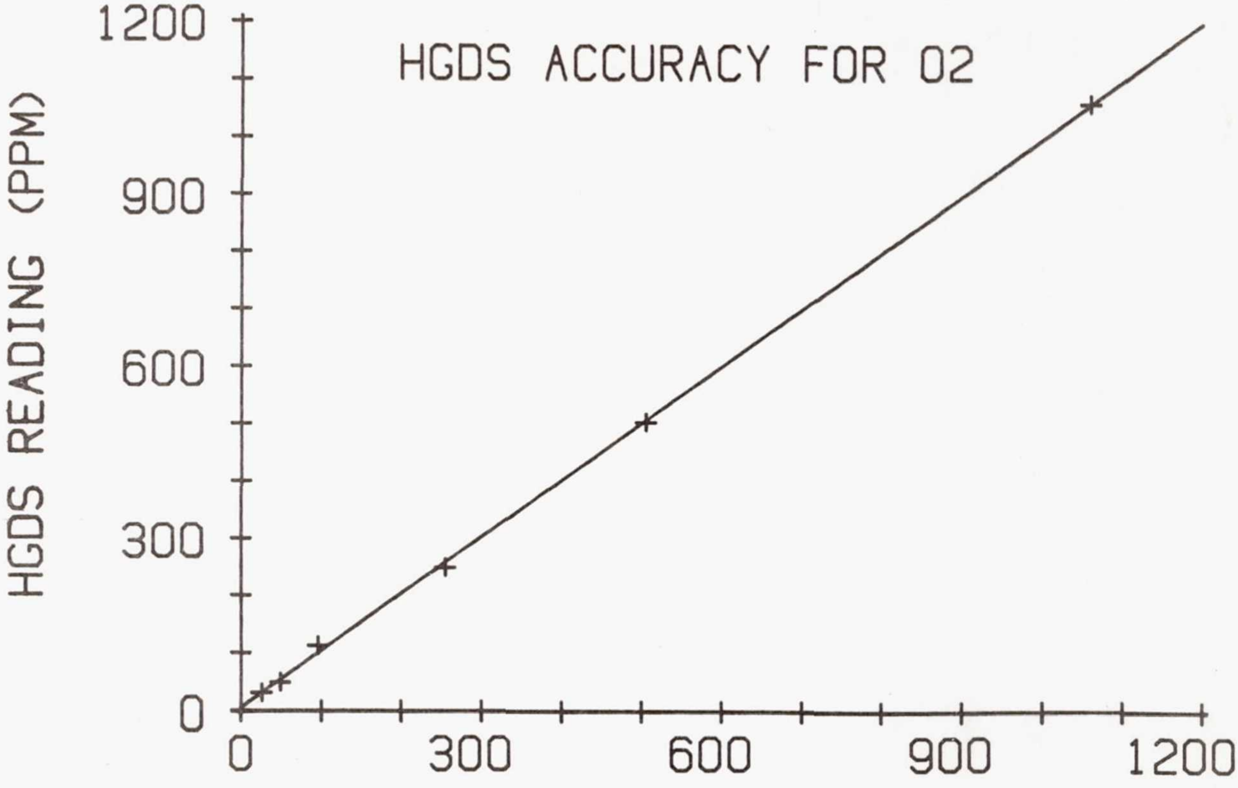

Figure 6.- Input O_2 conc. (PPM).

TABLE 2. HGDS ACCURACY AND PRECISION FOR OXYGEN

Theoretical Concentration	HGDS Reading (Average)	Error (Average)	Standard Deviation	Number of Samples
3640 ppm O_2	3696 ppm	+56 ppm	13 ppm	6
1060 ppm O_2	1056 ppm	-4 ppm	23 ppm	8
505 ppm O_2	502 ppm	-3 ppm	8 ppm	16
255 ppm O_2	249 ppm	-6 ppm	9 ppm	19
96 ppm O_2	113 ppm	+17 ppm	3 ppm	19
49 ppm O_2	49 ppm	0 ppm	2 ppm	16
26 ppm O_2	31 ppm	+5 ppm	3 ppm	20

DRIFT

The HGDS was operated without operator intervention for 12 hours. Data was read hourly. The system alternately sampled a test gas cylinder and a zero gas (pure GN_2) cylinder. Worst case peak to peak drift for any one-hour period, and for the entire test, are reported in Table 3, and shown in Figure 7.

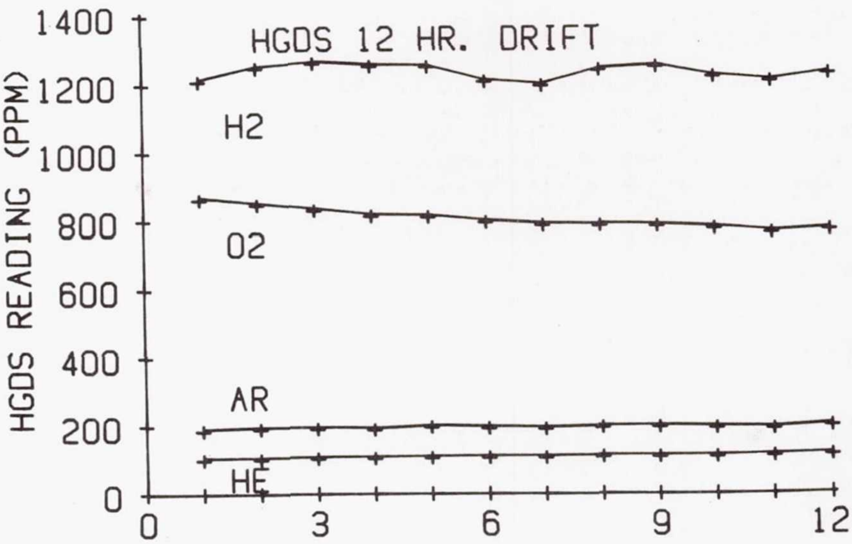

Figure 7.- Time (hours).

TABLE 3.

Gas	Test Gas Concentration	1-Hour Drift	12-Hour Drift
H_2	1060 ppm	44 ppm	66 ppm
He	105 ppm	2 ppm	10 ppm
O_2	1060 ppm	17 ppm	95 ppm
Ar	196 ppm	7 ppm	10 ppm

DESIGN IMPROVEMENTS

Like many computer-based systems, the HGDS has suffered from AC power line noise. Due to excessive noise on the Mobile Launcher Uninterruptible Power System (UPS), the HGDS was placed on a dedicated mini-UPS, which solved the power related problems.

The HGDS uses an ion pump to achieve the requisite vacuum of one-billionth of an atmosphere. This type of pump is susceptible to eventual hydrogen saturation and subsequent spontaneous, periodic elution, called "burping". This causes a degradation of measurement precision. The only solution is replacement of the ion pump. A recent modification has made this a simple, risk-free, one-hour procedure.

Several minor microprocessor firmware "bugs" have been identified and corrections are in work. Component faiures have been within acceptable limits.

APPLICATIONS

The HGDS is used to make critical go - no go decisions during the Space Shuttle countdown. The Launch Commit Criteria Document specifies the maximum allowable limits. A concentration of 8ØØ parts per million of hydrogen or oxygen is considered unacceptable for flight. Leakage of this magnitude at preflight propellant pressures could indicate a leak which would create flammable conditions when the propellants are at the much higher flight pressures. A concentration of 1Ø,ØØØ parts per million of hydrogen or oxygen (25% of the lower flammable limit) is considered an immediate on-pad hazard.

The most notable success of the HGDS was the detection of hydrogen leaks on two of Challenger's main engines during the STS-Flight Readiness Firings, as shown in Figure 8. In the ensuing investigation, incipient leaks were found in the third Challenger engine, and in a spare engine. All three engines were ultimately removed and repaired, thus avoiding a potential catastrophe.

As a result of lessons learned during the STS-6 hydrogen leak investigation, the accuracy and sensitivity of the HGDS is now used to perform an in-place end-to-end helium leak check on the entire Orbiter Main Propulsion/Engines system. In addition, the HGDS will be used to leak check the ground-to-Orbiter hydrogen and oxygen umbilical disconnects. It replaces a laboratory gas chromatograph and operator which were previously flown in from California before each launch to perform the leak check.

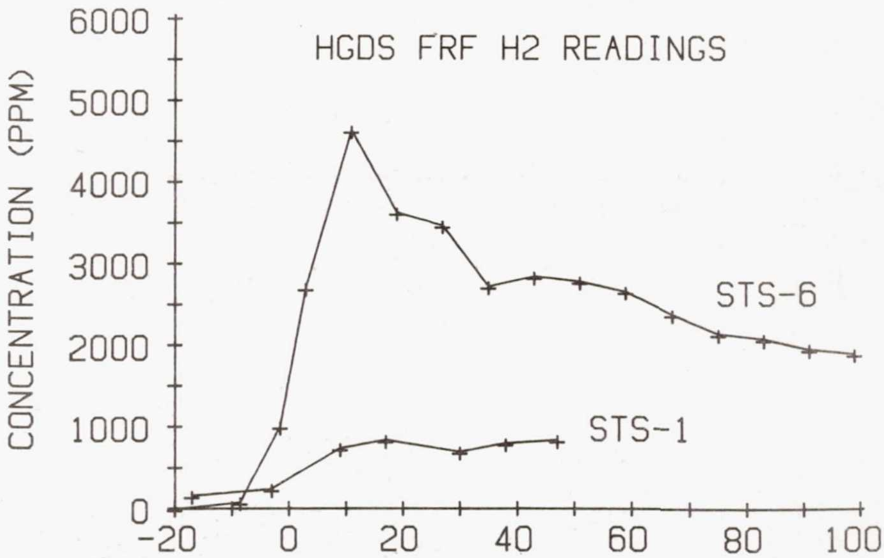

Figure 8 T-time (seconds).

CONCLUSIONS

The HGDS is an accurate, stable, and sensitive analytical instrument. It can make reliable measurements of a variety of gases at a few parts per million. Launch vibration has caused only one minor failure in six launches. Calibration can be verified and refreshed in real time, thus allowing high confidence to be placed in the data. It has demonstrated its importance to the Space Shuttle program by detecting leaks which, if uncorrected, could have caused a catastrophe. With the advent of cryogenic payloads such as Centaur within the Space Shuttle Payload Bay, that importance can only increase.

REFERENCES

1. Perry, C. L., Personal Communication

2. Perry, C. L., Krupnick, A. C., and Harwell, R. J.: Design and Development of the Hazardous Gas Detection System for Launch Vehicle Propellant Loading and Checkout. NASA TM X-53720, 1968.

3. Helms, William R. and Raby, Bruce A., "a Prototype Hazardous Gas Detection System for NASA's Space Shuttle", 26th Annual Conference of American Society for Mass Spectrometry, St. Louis, MO, May, 1978.

4. Bunyard, G. B., Wells, P., Jewhurst, F., and Raby, B. A., "Hazardous Gas Detection System for Space Shuttle", Instrument Society of America National Conference, Chicago, IL, 1979.

REFERENCES (CONT)

5. Wells, P., "A Microprocessor-Controlled Hazardous Gas Monitor", UTI Journal, Vol, 3, No. 2, 1980.