N91-28069

AI MASS SPECTROMETERS
FOR SPACE SHUTTLE HEALTH MONITORING

F. W. Adams

NASA
Mail Code DL-ESS-24
Kennedy Space Center, Florida

BACKGROUND

Modern rocket development in the United States formally began in 1914 with Dr. Robert Goddard's patents on the concept of utilizing liquid nitrous oxide for the oxidizer and gasoline for fuel in self-contained, change of momentum based, main propulsion systems (1). His first flight, with hardware using gasoline and liquid oxygen, did not occur until 1926, some 12 years later. German acquisition of the concept prior to World War 11 led to Dr. von Braun's development of the V-2, powered by liquid oxygen and alcohol. Post war U.S. development of the Redstone, Jupiter, Atlas, Apollo, Shuttle, and ultimately, Advanced Launch System (ALS) are the historical background for this presentation.

Development of the concept of using liquid hydrogen for fuel began in 1960 with the beginning of the Apollo program. Fuels used prior to this were hydrocarbons (alcohol, kerosene, jet fuel), or solids. There is approximately a 700:1 volume reduction achieved by converting gaseous hydrogen at room temperature to liquid at cryogenic temperatures. The increase in specific impulse for hydrogen/oxygen over hydrocarbon/oxygen fuels is approximately 1.5:1. (2) The choice of hydrogen for fuel imposed greatly increased hardware requirements for being able to identify and evaluate leaks.

Shuttle is the first system where liquid hydrogen was used in the liftoff stage of the propulsion system. It is boosted by detachable solid rocket motors to help attain orbit. The launch countdown formally begins 3 days prior to liftoff, and the loading of cryogenic hydrogen and oxygen begins about 11 hours prior to liftoff. During launch countdown, ground support systems are prepared for use by verifying that they are functional and capable of holding a calibration. They are then carefully maintained "powered up", and watched for problems as the count continues.

INTRODUCTION

Mass spectrometers were first used in a ground support role in 1964 for Saturn I launch vehicle testing, for identifying hydrogen leakage in the main propulsion system of the S-IV second stage, during cryogenic operation (3). Early instruments for Saturn centered around a magnetic sector type analyzer. Shuttle instrumentation is based on quadrupole and magnetic sector type mass spectrometers. Other types of hydrogen detectors, while capable of locating and quantifying hydrogen leaks at low levels, are not usable above approximately 10% hydrogen concentration, and are unable to differentiate oxygen leaks from air intrusion, which the mass spectrometer can do. A recent patent, #4,953,976 based on Raman scattering, is the nearest technology to the mass spectrometer, for use in this type of service.

Mass spectrometers can be made to be sensitive to helium, the purge gas used in liquid hydrogen systems. Helium is also used as the trace gas (for safety reasons, during testing, when hydrogen is not present) as an aid in flagging and locating leaks. The general utility of the ruggedized mass spectrometer as a process instrument, as opposed to a laboratory curiosity, has led to its' increased use in facility ground support equipment to enhance the visibility of flight hardware with respect to liquid hydrogen and oxygen leakage.

Facility mass spectrometers were not installed for the classical liquid oxygen / hydrocarbon main propulsion system ground support equipment (GSE). In these systems, mass spectrometers existed in the form of drag-on helium leak detectors, using helium as a trace gas. They were not used to sense fuel leaks directly. Permanent, facility analyzers, were installed for Shuttle because it is powered by liquid hydrogen, which produces leaks in real time, that cannot be detected by use of classical helium leak detectors.

MASS SPECTROMETER INSTALLATIONS AT KSC

The facility Hazardous Gas Detection System (HGDS) at Kennedy Space Center, Florida (KSC), is a mass spectrometer based gas analyzer (4). Two instruments make up the HGDS, which is installed in a prime/backup arrangement, with the option of using both analyzers on the same sample line, or on two different lines simultaneously. It is used for monitoring Shuttle during fuel loading, countdown, and drainback, if necessary. The system is located in the mobile launch platform, underneath the vehicle, and must sustain the shock and vibration of launch. It must be operational during main engine firing for flight readiness firings (FRF), and after main engine firing, for launch, in order to perform during de-tanking, if launch is aborted.

HGDS is controlled and monitored, during countdown, from the Launch Control Center approximately four miles away. It was HGDS that discovered the hydrogen leaks in STS-6 Flight Readiness Firing (FRF), and STS-35 and STS-38 launch attempts, while monitoring the aft compartment of the orbiter.

Four compartments on the flight vehicle are monitored for their fraction of hydrogen, helium, nitrogen, oxygen, and argon. These are the External Tank/Inter-tank area, Payload Bay, Mid-body and Aft compartment. One sample is drawn from the hydrogen tail service mast (TSM). The presence of anything but nitrogen indicates main propulsion system, payload, fuel cell, or ground support hardware system leakage respectively. Launch Commit Criteria (LCC's), are determined prior to tanking, for the amount of each gas that will be allowed without taking action in some form.

Samples from the various compartments are pulled down dedicated stainless steel lines by small diaphragm type pumps. A sample switching arrangement, utilizing remotely controlled valves, is used to direct the sample to the analyzer. In order to reduce the time required for the sample from a particular area to reach the analyzer, a system of differential-flow / pressure-reduction stages are used. Disruption of flow in the sample delivery system can cause the analyzer to report data on a non-representative sample, and thereby give a distorted picture of the status of the vehicle.

Additional mass spectrometers have been added, as facility hardware, to monitor the 17 inch hydrogen orbiter/ET disconnect for flight readiness firings, special tanking tests, and launch. Plans are in process to add mass spectrometer capability to monitor the hydrogen fill and drain lines on the ground side, to more quickly determine the state of purge before and after fueling operations. A miniature, ruggedized flight version of the facility mass spectrometers is in the prototype stage at this time, and may some day be flight hardware. Mass spectrometers have flown in space aboard satellites and planetary probes since the beginning of the program.

THE NEED FOR ARTIFICIAL INTELLIGENCE (AI)

The use of complex instruments, operated over many shifts, by different people, in a flexible operational environment, has caused problems in tracking status of GSE and the vehicle. A requirement for overall system reliability has been a major force in the development of Shuttle GSE, and is the ultimate driver in the choice to pursue AI techniques for Shuttle and ALS mass spectrometer systems. The need for certainty that the numbers displayed on the operators' console are truly representative of the variables that are being measured, is critical.

SHUTTLE APPLICATIONS OF AI

There are five areas that have been identified, where AI techniques. can help solve KSC's problems for Shuttle. First is the pre-launch system validation. It takes about two weeks to validate HGDS for launch. This involves a complete check of critical system voltages, gain and offset adjustments in critical stages, verification of the amount of consumables (calibration gases), redundant circuitry checks (filaments in the ionizer, vacuum gages, etc.), and verification of normal operation, both locally, and from the remote control stations in the firing rooms. Many parts of this operation can be automated. Use of an Advisor here would be to guide personnel through the instrument checkout procedures.

Second, is the reduction of display complexity, as seen by the operators and users, during operations. This is a serious problem when more than one mass spectrometer display must be viewed simultaneously. Often two instruments are used to look at the same sample to verify that the data is consistent. An ideal display driver would indicate only the gas concentrations on the sample lines and would have the mass spectrometer function completely transparent to the operator. An Advisor here would provide visibility of background functions when problems occur, as a console operator aid. Near real time operation here is a firm requirement. Figure 1 shows the current display for the HGDS console for Shuttle. Figure 2 shows the actual variables (function designators) displayed, and where they appear on the screen.

Third, is the requirement to verify that samples from the vehicle are within the allowed limits, LCC'S, which normally vary, depending on the state of loading. During countdown, console operators are constantly looking at the data for clues that there might be something wrong with the it. The sample seen by the analyzer must be representative of the environment around the hardware being evaluated for leaks. There must be no unknown system hardware failures which might distort the readings seen by the operators. An Advisor here would comment on the certainty of the data, including cross correlation between other instruments that might be looking at the same gas stream. Historical data from earlier launches could be referred to if deemed significant. Near real time performance is required at this phase.

LCC's are sometimes real-time variables, depending on the situation, and must be constantly observed in this light. LCC's for hydrogen, oxygen, and helium concentration, apply to ground and flight hardware during cryo loading sequences up to liftoff, or drainback and boiloff, if launch is not possible. The vehicle data is monitored by many knowledgeable persons at different locations on KSC and at other NASA centers (JSC, MSFC), and it is important, for this reason, that this data be representative and reliable. System oversight by knowledgeable instrument operators is necessary because data users will not normally be aware of abnormal system operation.

The fourth requirement is that real time troubleshooting of one of these systems (not to mention three or four), is a major undertaking, particularly when being performed simultaneously with launch support. KSC Design Engineering personnel, in coordination with operations, are developing techniques and special test sequences that will improve the console operators' ability to perform advanced troubleshooting during countdown, to verify whether a problem is in the vehicle or the analyzer, and evaluate the impact on the launch operation. As a side note, the first thing the data users question is not their system, but the integrity of data that indicates hardware problems. The advisor here would suggest testing routines that could be run real time while the system is still gathering data in support of the launch countdown.

The fifth and last application of AI is a tool for training new operators and upgrading skills of those familiar with the instruments. One serious problem with complex hardware is the limited number of people who understand specific instruments. During high pressure situations, where testing of a vehicle on one pad is being worked simultaneously with either testing or launching on another, skilled personnel are in short supply. Often the skills required for launch and testing are different, and less skilled people can be effectively used in testing situations. Allowing less skilled personnel to operate the system quickly can be a tremendous benefit to operations, provided everyone knows their limits and responsibilities. Here the advisor would track progress and advise operators where they need additional training to become proficient.

CONCLUSION

It should be emphasized here that a specific instrument or capability will be installed for Shuttle only because the launch system cannot reliably function without it. AI would not normally be applied to a hazard warning system at KSC if it did not offer a significant advantage over manual methods of tracking problems and reducing data in real time.

The burden of operating multiple mass spectrometers has increased greatly with each new system installation. The proper response to the situation is not to bring in more people, as there are only limited facilities in the firing rooms (console screen space, personnel access, etc.). ALS GSE will be deployed with similar motivation.

Shuttle has been used as a testbed for conceptual aspects of mass spectrometer application development for ALS. One reason that teams at KSC were ready to support special testing, when the latest group of leaks was discovered on Shuttle, was that personnel were looking at advanced applications of mass spectrometer systems in preparation for a demonstration of hardware for ALS.

In support of Shuttle and development for ALS GSE, it is important to keep the target in mind when designing a system of this magnitude. One is constantly being distracted by peripheral operations and special test support that are going on in parallel with system development. Often, new concepts are identified in these situations, and it is tempting to try to incorporate everything learned into new GSE.

Real system requirements must be kept isolated and not changed during system development. Experience with Shuttle has indicated that certain failure modes are more likely to occur than others. Equipment design must be based on knowledge of the hardware (what it is, how it is used, how it has failed in the past), and what kinds of surprises were seen when previous systems were installed. The ability to zero in on requirements, up front, is the key to achieving high and successful launch rates, in present and future systems.

BIBLIOGRAPHY

1. Robert Goddard, Pioneer of Space Research, Dacapo Series of Space, Dacapo Press, Inc., Subsidiary of Plenum Publishing Corp., 1963.

2. Starr, Stan, Personal conversation, 10/02/90.

3. Helms, W. R., History, Design and Performance of the Space Shuttle Hazardous Gas Detection System, Space Shuttle Technical Conference, NASA Conference Publication 2342, Part 1, 1983.

4. Helms, W. R. & Raby, B. A. A prototype Gas Detection System for NASA's Space Shuttle. 26th Annual Conference on Mass Spectrometry and Allied Topics, 1983.

APPENDIX A: SOFTWARE USED IN SYSTEM DEVELOPMENT

GOLDWORKS: (GOLDHILL COMPUTERS, INC., EXPERT SYSTEM INTEGRATED DEVELOPMENT ENVIRONMENT.)

LISP DEVELOPMENT ENVIRONMENT FOR GENERAL PROTOTYPING AND PRELIMINARY MODELING

CXPERT: SOFTWARE PLUS, LTD, CROFTON, MD.

EXPERT SYSTEM DEVELOPMENT ENVIRONMENT COMPATIBLE WITH THE GOAL OF ROMMING THE EXPERT SYSTEM VIA DOS OR UNIX. RULES, DATA BASE, INFERENCE ENGINE.

OS-9: MICROWARE CORP., DES MOINES, IOWA

ROMMABLE OPERATING SYSTEM AND DEVELOPMENT ENVIRONMENT

ZORTECH C++: ZORTECH CORP., WOBURN, MASS

AUXILIARY DEVELOPMENT, COMMUNICATION AND GRAPHICS INTERFACE, CXPERT SUPPORT, ETC.

SALIENT HARDWARE FEATURES

ROMMED OPERATING SYSTEM AND APPLICATIONS FOR OPERATION IN A HIGH SHOCK AND VIBRATION ENVIRONMENT.

APPENDIX B: HARDWARE USED

COMPAQ 386/LISP AND GRAPHICS TERMINAL

68030/TARGET EMBEDDED PROCESSOR TO BE USED IN THE LAUNCH ENVIRONMENT (FORCE/VME, GESPAC)

GMX / 68020 GMX CORP., CHICAGO, IL

MGA-1200 MASS SPECTROMETER, PERKIN ELMER CORPORATION

APPENDIX C: GODDARD'S PATENTS RELATIVE TO ROCKET PROPULSION DEVELOPMENT

	FIRST EVIDENCE OF RUSSIAN INTEREST IN ROCKETRY	1881
	TSIOLKOVSKY, INVESTIGATION OF SPACE BY MEANS OF ROCKETS	1903
11 02653	MULTI STAGE ROCKET	07/07/1914
11 03503	BREECH BLOCK TO INJECT SUCCESSIVE CHARGES, COMBUSTION CHAMBER, NITROUS OXIDE, ETC	07/14/1914
	GODDARD, A METHOD OF REACHING EXTREME ALTITUDES	1919
	GODDARD AWARE THAT GERMANY WAS INTERESTED IN ROCKETRY ALSO	1923
	OBERTH FIRST PUBLISHED	1924
1879186	IGNITION OF LIQUID FUEL, CURTAIN COOLING	09/27/1934
1879187	GYROSCOPIC STEERING	09/27/1934

APPENDIX A: SOFTWARE USED IN SYSTEM DEVELOPMENT

GOLDWORKS: (GOLDHILL COMPUTERS, INC., EXPERT SYSTEM INTEGRATED DEVELOPMENT ENVIRONMENT.)

LISP DEVELOPMENT ENVIRONMENT FOR GENERAL PROTOTYPING AND PRELIMINARY MODELING

CXPERT: SOFTWARE PLUS, LTD, CROFTON, MD.

EXPERT SYSTEM DEVELOPMENT ENVIRONMENT COMPATIBLE WITH THE GOAL OF ROMMING THE EXPERT SYSTEM VIA DOS OR UNIX. RULES, DATA BASE, INFERENCE ENGINE.

OS-9: MICROWARE CORP., DES MOINES, IOWA

ROMMABLE OPERATING SYSTEM AND DEVELOPMENT ENVIRONMENT

ZORTECH C++: ZORTECH CORP., WOBURN, MASS

AUXILIARY DEVELOPMENT, COMMUNICATION AND GRAPHICS INTERFACE, CXPERT SUPPORT, ETC.

SALIENT HARDWARE FEATURES

ROMMED OPERATING SYSTEM AND APPLICATIONS FOR OPERATION IN A HIGH SHOCK AND VIBRATION ENVIRONMENT.

APPENDIX B: HARDWARE USED

COMPAQ 386/LISP AND GRAPHICS TERMINAL

68030/TARGET EMBEDDED PROCESSOR TO BE USED IN THE LAUNCH ENVIRONMENT (FORCE/VME, GESPAC)

GMX / 68020 GMX CORP., CHICAGO, IL

MGA-1200 MASS SPECTROMETER, PERKIN ELMER CORPORATION

APPENDIX C: GODDARDS' PATENTS RELATIVE TO ROCKET PROPULSION DEVELOPMENT

	FIRST EVIDENCE OF RUSSIAN INTEREST IN ROCKETRY	1881
	TSIOLKOVSKY, INVESTIGATION OF SPACE BY MEANS OF ROCKETS	1903
1102653	MULTI STAGE ROCKET	07/07/1914
1103503	BREECH BLOCK TO INJECT SUCCESSIVE CHARGES, COMBUSTION CHAMBER, NITROUS OXIDE, ETC	07/14/1914
	GODDARD, A METHOD OF REACHING EXTREME ALTITUDES	1919
	GODDARD AWARE THAT GERMANY WAS INTERESTED IN ROCKETRY ALSO	1923
	OBERTH FIRST PUBLISHED	1924
1879186	IGNITION OF LIQUID FUEL, CURTAIN COOLING	09/27/1934
1879187	GYROSCOPIC STEERING	09/27/1934