Commercialization of Kennedy Space Center Instrumentation Developed to Improve Safety, Reliability, and Cost Effectiveness of Space Shuttle Processing, Launch, and Landing

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INTRODUCTION

The top priority at Kennedy Space Center (KSC) is safety of the flight crew and Shuttle vehicle. This priority is followed by safety of the personnel and physical assets of KSC, and reducing the costs associated with processing the Shuttle and other flight components, driven by budget and down sizing pressures. The KSC Instrumentation Laboratories, managed and staffed by both civil service NASA personnel and by I-NET, the Engineering Support Contractor, help ensure the accomplishment of these priorities by adapting or developing technologies to improve operational safety and decrease processing costs. The Laboratories are organized by technical discipline into nine laboratory teams, each being generally self contained with highly skilled scientists, engineers, and technicians providing the skills necessary to conceive, develop and test innovative technical solutions. The laboratories are the Hazardous Gas Detection Laboratory specializing in the detection of cryogenic propellants using mass spectrometer-based instruments; the Toxic Vapor Detection Laboratory providing very low level detection capabilities for highly toxic hypergolic propellants and other chemicals; the Landing Aids Laboratory which develops navigation and positioning systems to calibrate Shuttle landing guidance systems; the Optical Instrumentation Laboratory specializing in development of low cost optical and ultrasonic instruments; the Transducer Development Laboratory which provides

sustaining engineering for the KSC inventory of process measurements; the Contamination Monitoring Laboratory which develops and tests clean room monitoring systems; the Special Instrumentation Laboratory and Special Development Laboratory which each develop and support instruments for non-destructive inspection; and the Data

Acquisition Systems Laboratory which provides and develops data acquisition, analysis and recording systems for special tests and permanent installations. These laboratories support all functional areas of KSC and each other in accomplishing a wide range of projects which are improving the techniques involved in processing and testing the flight systems to ensure that the Shuttle remains the prime human space flight system well into the next century.

The technology solutions produced by the laboratories to solve specific Program problems are often highly innovative and potentially useful to the commercial sector. NASA has recently stepped up its roll in transferring technologies with the purpose of creating jobs and enhancing America's competitiveness in global markets. This process is also useful to NASA by allowing it to reduce development cost, by sharing that cost with a commercial concern, and reducing life cycle costs, by procurement of commercial off-the-shelf (COTS) technology with the benefits of an after market infrastructure, lower pricing, and warranties. NASA uses two types of vehicles to accomplish these goals called Dual Use and Spin-Off. Dual Use Agreements are jointly funded technology development initiatives to produce products that meet both NASA and commercial partner requirements. Spin-Offs involve the transfer of completed technologies to industry via licensing or other technology transfer mechanisms. This paper reviews some of the technologies that have been or are in the process of technology transfer, and discusses routes by which commercial concerns can obtain licenses to other Instrumentation Laboratory technologies.

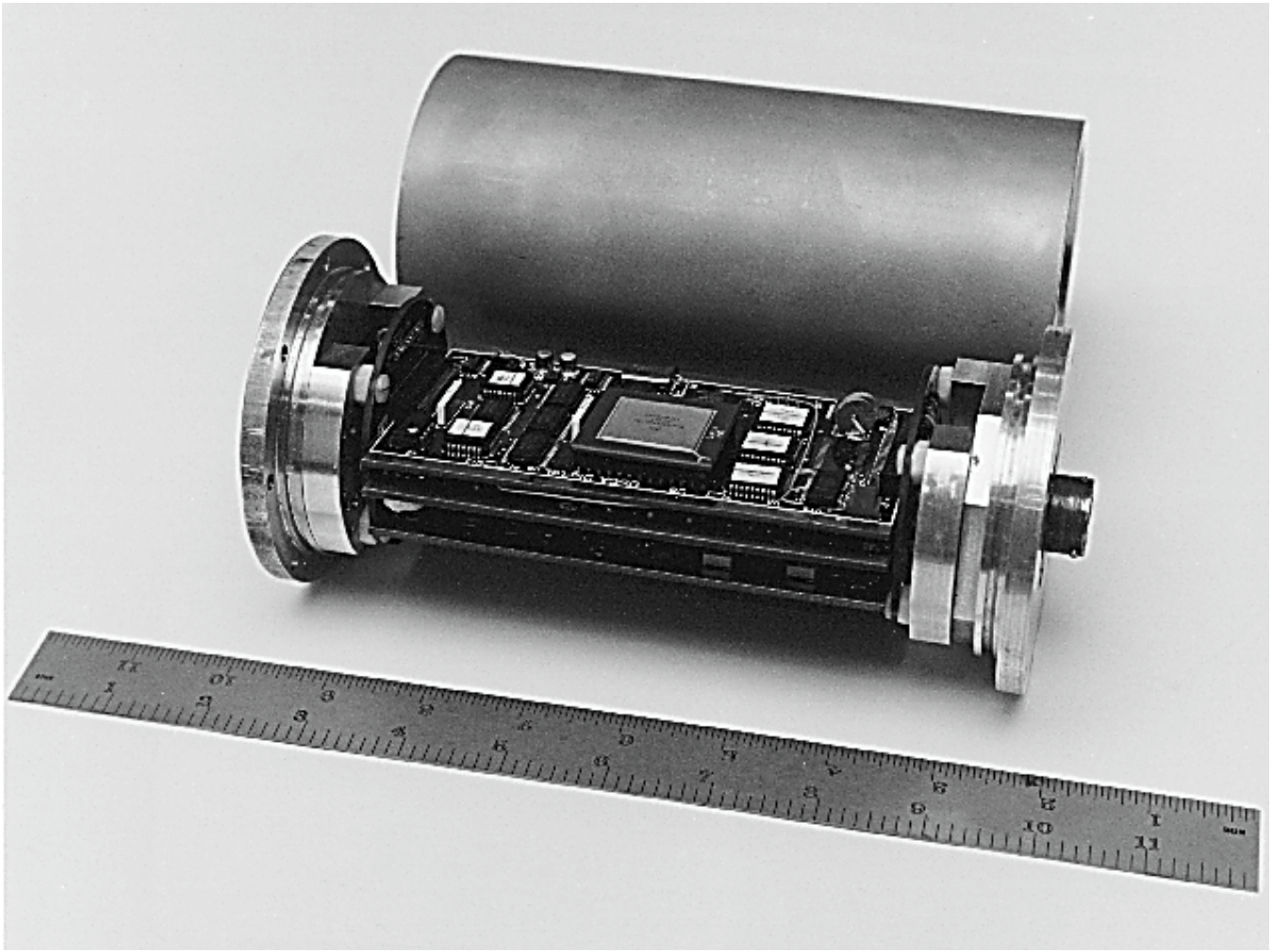
ADVANCED DATA ACQUISITION SYSTEMS

Each Shuttle launch pad is equipped with a facility data acquisition system called the Permanent Measurement System, for monitoring structural responses, acoustic levels, transient temperatures and other environmental effects of the launch environment. This system can support up to 600 measurements per Pad during a launch and measurements from the Vehicle Assembly Building (VAB). The VAB measurements relate to solid rocket booster stacking loads on the hold down posts. Typical measurement numbers are 200 channels per launch. The system records data at different rates per channel for a short period preceding lift-off. The PMS hardware is of 70's vintage, was installed in the early 80's, and has been used in all launches since the sixth Space Shuttle mission in 1983. We began seeking replacement technology in the 1990 time frame with two projects, one called Smart Cable Technology and another called Self-Calibrating Measurements. The concept of the Smart Cable project was to imbed a chip into large cable connectors (60 pin typically) and develop a means for the chip to communicate with other cable connector chips and somehow identify the assignment of each conductor in the cable. With this approach it was hoped to achieve a system of cabling that could be simply hooked up in the field allowing a remote operator to identify the configuration of the measurement channels carried by the cable. The concept of the Self Calibrating Measurement was to design a system that could identify a connected measurement and by injecting signals or varying excitation voltage, perform a rough in-place calibration or health verification of the measurement.

The result of these efforts was a concept to install a chip, called Tag-RAM, into a short cable pigtail which would contain the calibration data. By using digital communications superimposed onto excitation conductors, a remote amplifier system could download the data thereby identifying the transducer and its calibration data. The features and capabilities of this amplifier grew and became what is now called the Universal Signal Conditioning Amplifier. The USCA, which has been described in detail elsewhere, is designed to be located in the environment close to the measurement, contained in a small ("coke can") cylinder designed to withstand 25 g's rms and a wide temperature range and still perform within stringent operating specifications. The USCA reads the transducer Tag-RAM and

automatically configures the gain, filter characteristics, linearization (7th order polynomial), and other features. These characteristics can be modified by a remote operator through the system known as Advanced Data Acquisition System which provides communications with the USCA's and merges their data streams into a PCM protocol for transmission back to the Launch Control Center.

The USCA concept was reported to KSC's Technology Projects Office in 1993 and published in NASA "Tech Briefs" magazine in 1994. The submission of a patent application in 1994 allowed NASA to offer the invention for licensing. This invention became KSC's first Dual Use Cooperative Agreement. In 1995, Loral Information Systems (now Lockheed Martin Telemetry and Information Systems) signed an agreement with the Florida Technology Research and Development Authority (TRDA) to commercialize USCA and thereby create high technology jobs in Florida. Further agreements with NASA provided co-funding for the commercialization effort. This three way funding structure allowed NASA to reduce its direct expenditures on USCA development by more than half and enable the future procurement of USCA units as COTS technology with the many benefits as mentioned earlier. Loral subsequently signed similar agreements for the Advanced Data Acquisition System technology. The NASA version (highly environmentally hardened) is now complete and commercially available while ADAS development continues. This Dual Use Agreement provided NASA a very large savings in development costs, a U.S. company with development cost savings for a potentially major product line, and the State of Florida with additional high technology jobs. The savings from implementing USCA/ADAS are projected to exceed $900,000 per year and will repay all development and acquisition costs within 1 1/2 years of project completion.



The compact and rugged USCA device.

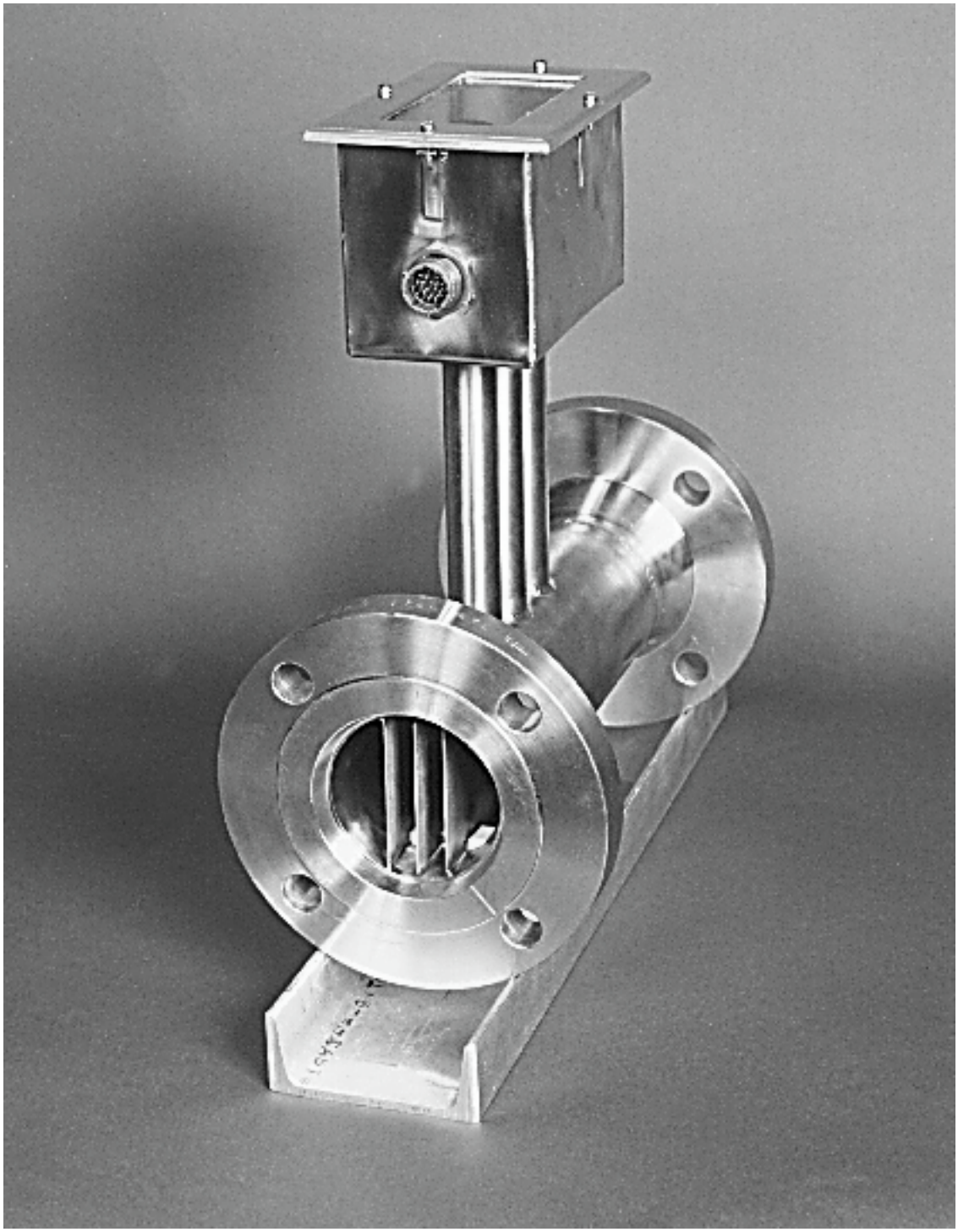
CRYOGENIC TWO PHASE FLOW METER

KSC handles large quantities of cryogenic liquids including liquid hydrogen, oxygen, and nitrogen. These commodities are very expensive and difficult to handle due to their low temperature and small latent heats of vaporization. The process of transferring a cryogenic liquid typically involves flowing the liquid at a slow rate to chill down the transfer line and receiving vessel then, when full liquid flow can be achieved, flowing at a bulk transfer rate. The boil-off vapor is vented to atmosphere and in the case of a flammable gas, such as hydrogen, burned off in a flare stack. The normal chill down process is controlled by monitoring temperatures in the transfer line and visual determination of how much liquid is flowing out the vent. This approach is both wasteful of commodity but can also result in too much vapor transferred into the receiving tank. Space Station hardware had, at one time, a very stringent accuracy requirement for pounds of cryogenic fluid loaded which exceeded the capability of normal transfer methods. A method for determining the "quality" or ratio of vapor mass to liquid mass in situ was required. Capaci-

tance measurement was investigated and it was found that oxygen and nitrogen have fairly large dielectric constants. Computations showed that two phase streams could produce a measurable effect on the capacitance of electrical plates placed in the flow stream. To first order, measuring the capacitance of a properly designed plate geometry would provide an indication of density, and given additional measurements such as temperature and pressure, the quality could, in principle be determined.

Cryogenic two phase flows tend to fluctuate rapidly, even occasionally reverse, so that a very rapid electronic means of capacitance measurement was required. The Optical Instrumentation Laboratory conceived of a unique method of very rapidly (kilohertz rate) measuring capacitance. Later, during actual flow tests with liquid nitrogen, when it became clear that the signal produced had a very high signal to noise ratio, it was proposed that a time correlation of two quality meters in series would produce a time delay indicative of velocity. This has proved to be the case, and a very high signal to noise correlation flow meter was produced.

Air Products, Inc. entered into a Dual Use Cooperative Agreement to co-develop the quality flow meter into a commercially viable mass flow metering system for cryogenic industrial gases. Tests have been performed at KSC and in Allentown, PA testing the capabilities of the latest version of the flowmeter. This innovative capacitance measuring system has been licensed to Air Products for industrial gas applications. The capacitance circuitry concepts are available for licensing for other applications.



Capacitor plates in the two-phase meter enable the measurement of vapor liquid ratio.

UV/IR FLAME DETECTOR

Each Shuttle launch pad includes a liquid hydrogen storage and transfer system for loading the External Tank and fuel cell systems. The system consists of a 850,000 gallon vacuum jacketed dewar, a vaporizer system to provide pressurization and flow, a 1500 foot length of 10 inch internal diameter invar vacuum jacketed transfer line, piping and valves on the Mobil Launcher Platform, the ET Vent Arm, a 700 foot length of double wall 18 by 20 inch vent pipe, and a flare stack where vented hydrogen gas is burned off in a propane flame. The piping associated with the vaporizer, transfer, and vent lines is monitored by 60 ultraviolet flame detectors, roughly one per mechanical joint. Additional flame detectors monitor the astronaut egress areas.

KSC has been using ultraviolet (UV) flame detectors since the Apollo-Saturn era, when engineers discovered that commercially available fire detectors do not reliably detect hydrogen flames. When hydrogen burns, hot water is produced, which results in UV emissions in the 200 nm band and infrared (IR) emissions in the 2.8 micron band. Commercial IR flame detectors are designed to operate in the hot carbon dioxide IR bands and are generally insensitive to hydrogen flames. Commercial UV/IR detectors also do not work because they require detection in both bands to alarm. KSC procures UV flame detectors from commercial sources and has worked with supplier engineers over the years to work out bugs and incorporate the latest technologies. As a result, the Shuttle pad flame detection system was extremely reliable and effective. When propellants engineers installed the flare stack, replacing the obsolete burn pond system, the UV detectors became prone to false alarms. Extensive testing of the detectors, both in the field and in the laboratory, revealed that the false alarms were due to the flare stack from reflections off the pipes and the overall sky brightening due to Rayliegh scattering in the UV. This investigation was very difficult because detectors that were completely blocked from direct view of the flare stack were alarming!

The solution developed by the Transducer Development Laboratory was to simultaneously measure the irradiance in the IR and UV, high pass filter each signal, then perform a correlation. This technique accomplishes two objectives. The high pass filtering eliminates slowly fluctuating signals produced by a very large flames such as the flare stack (and its reflections). Second, by correlating the outputs of both sensor systems, rather than performing an “and” logic operation on their outputs, a more reliable detector is produced. The use of a second IR channel is under investigation as a further discriminator of the distance to the flame. This system is under joint development with Scientific Instruments under a Dual Use Agreement and is expected to become a commercially available product early next year.

The UV/IR Flame Detector correlates the response of UV and IR detectors to eliminate false alarms.

FTIR SOFTWARE

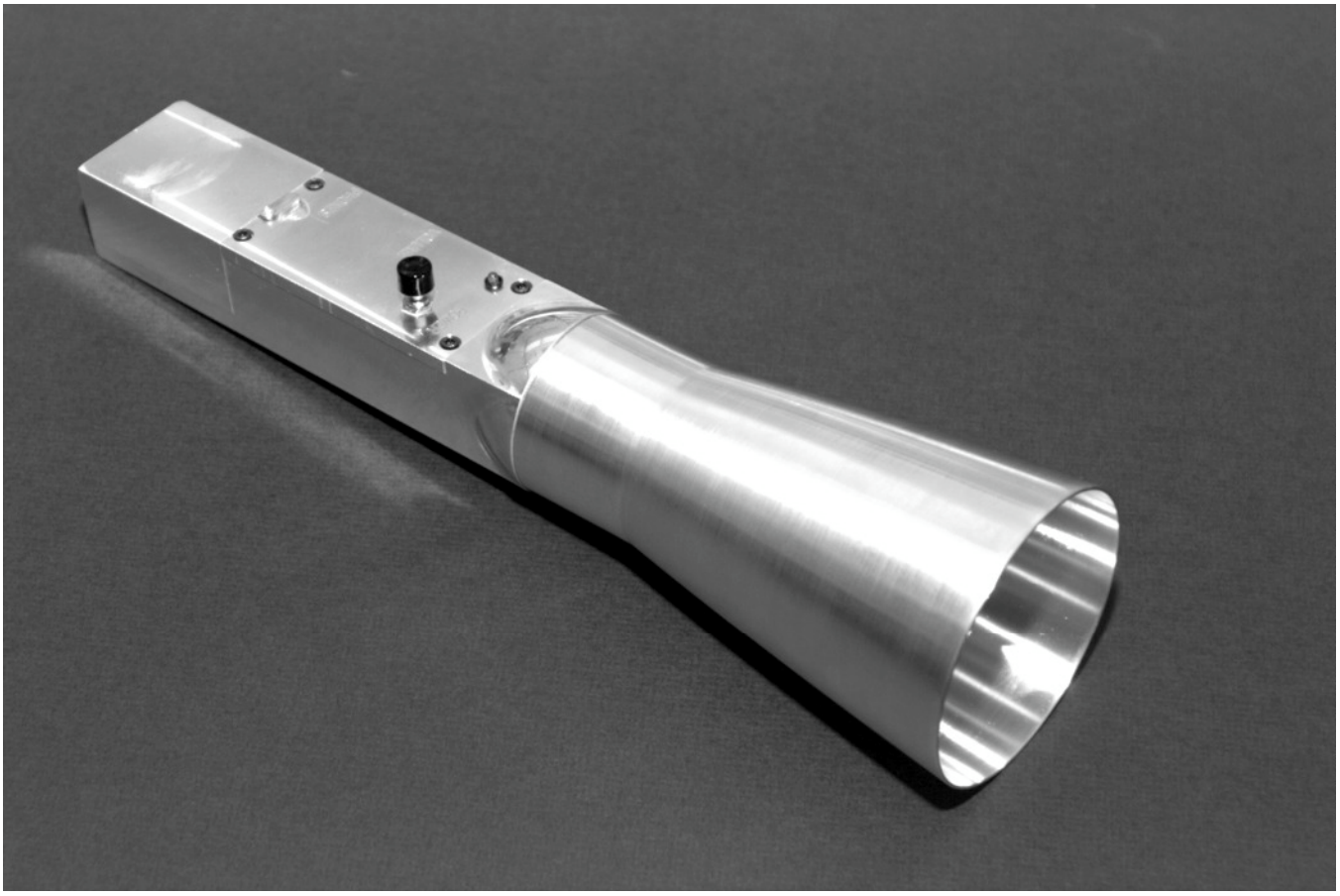
The Toxic Vapor Laboratory and Contamination Monitoring Laboratory tested a large number of analytical instrument technologies for field monitoring of hypergolic propellants, ammonia, and other toxic substances used in the Space Program. Their research showed that the Fourier Transform Infrared Spectrometer (FTIR) technology was

highly effective when the target gases produce a rich mid-IR absorption spectrum, the end-use requires only moderate sensitivity (ppm and higher), ability to reject interfering chemical species, and long term maintenance-free stability. The FTIR operates by introducing the gas sample into an absorption cell which contains mirrors at both ends to bounce a beam of light back and forth across the volume many times to provide a long path length for absorption. The FTIR provides a light source (IR) and receives the attenuated beam into an interferometer box. The interferometer includes moving mirrors which causes the beam to self-interfere producing a varying light intensity as the mirrors separate. By performing a fourier transform on the intensity versus spacing data, a spectrum of intensity versus wavelength is obtained. Features in the spectrum indicate the presence of various substances and the depth of the features indicates the chemical concentration of the species. The mathematical problem of extracting the list of species and their concentrations from the raw data record is difficult and time consuming even for a computer. These methods also require various corrections to the raw data to avoid errors.

The lab personnel were not satisfied with the technical approach to this solution which was performed by the three FTIR's tested. New algorithms were conceived and tested, for calibrating, analyzing unknown samples, correction of baseline errors, correction for temperature drift, degradation of the optics, and corrections for non-linearity. The units in use in the lab were retrofitted with new computers and software which increased their dynamic range, accuracy, and greatly improved response time. These modifications allowed us to select and modify commercially available FTIR's to meet the needs for monitoring for dangerous hypergolic leaks on the Pads, ammonia leaks in Space Station systems, and concentrations of the Orbiter tile waterproofing compound DMES. Midac, one of the tested FTIR manufacturers, has a Space Act Agreement with NASA to further the development of this software.

ULTRASONIC LEAK DETECTION

Gas leaks produce high frequency sound beyond the upper limit of human hearing in the so called ultrasonic range of frequencies. The technology of detecting and locating gas leaks has been in use for some time both hand-held systems and facility fixed systems. In 1990, two Shuttle missions were grounded with hydrogen leaks in the aft compartment and around the 17 inch disconnect. The Instrumentation Laboratories developed small ultrasonic leak detectors using reflectors (cut from the bowls of hallway ashtrays!) to focus the ultrasound to improve detectability and improve the direction finding ability. These units were mounted on remote control cameras in the Orbiter aft during leak tests. These units eventually evolved to the current units which use a different type of reflector but still concentrate the ultrasound and effectively localize its direction. These are now in use in many areas of flight hardware processing and have located leaks on the Shuttle Main Engines and in the Space Lab air lock connection among others. This detector converts the ultrasound to audio thereby allowing a user to listen to the world in the 40kHz range, where gas leaks into the atmosphere emit significant sound. This system is also being evaluated by the United States Air Force and has been approved by the Johnson Space Center for use onboard the Space Shuttle. An exclusive licensing agreement has been signed with UE Systems, a leading manufacturer of ultrasonic detection systems, to allow them to incorporate the circuitry and reflector improvements into their product line.



The directional cone on the Ultrasonic Leak Detector increases sensitivity and helps pinpoint the leak source.

SUMMARY

The Instrumentation Laboratories report, on an average, 17 new technical advances each year to the KSC Technology Programs and Commercialization Office. This office must select those advances with the most commercial promise to continue forward through either the Dual Use Program or Spin-Off Program, then follow through a process of publishing in NASA's "Tech Briefs" magazine. Those with the greatest commercial promise are submitted for patenting and widely offered to industry for licensing. The above five case histories represent a sampling of 3 Dual Use Agreements, 2 Licenses, and 2 Spin-Offs which KSC has thus far secured, based upon Instrumentation Laboratories developed technologies. The Laboratories expect to continue this dual role in solving specific Program problems and creating technologies that benefit our nation in broader ways.