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Paper Session III-A - Advanced Development of Ground Instrumentation as a Key Strategy in Improving the Safety and Efficiency of Space Shuttle Checkout and Launch

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Advanced Development of Ground Instrumentation as a Key Strategy in Improving the Safety and Efficiency of Space Shuttle Checkout and Launch

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INTRODUCTION

This paper describes some of the advanced technology instruments produced by the Instrumentation Development Laboratories at Kennedy Space Center. These systems contribute to the realization of the goals of “better, faster, cheaper” set by the NASA Administrator and provide a steady stream of inventions which benefit the commercial marketplace through NASA’s Commercialization and Dual Use Programs. The paper discusses advanced sensors and systems developed in the technical disciplines of cryogenic and toxic gas detection, leak location, hydrogen flame detection, data acquisition, navigation and positioning, payload contamination monitoring, non-destructive inspection, and the specific contributions made to improve safety and efficiency of the Space Shuttle checkout and launch process. These technologies are available to other government programs or for technology transfer to the commercial sector.

CRYOGENIC GAS LEAK DETECTION

The Hazardous Gas Detection System (HGDS) is a mass spectrometer-based instrument located on each mobile launch platform and is used to detect part per million (ppm) levels of cryogenic vapor leaks in several Space Shuttle purged cavities during the launch countdown. After cryo-loading begins, samples of purge gas from the External Tank (ET) inter-tank cavity, Orbiter mid-body, payload bay, and the Orbiter Aft Fuselage are transported by vacuum sample lines to the HGDS where the concentrations of hydrogen, helium, oxygen and argon are measured. Low ppm sensitivities are required due to the high purge rate of nitrogen gas and the resulting high dilution of the sample, plus the fact that pre-launch leak rates can increase dramatically as the engines reach flight pressures.

During the Flight Readiness Firing (FRF) for the first Challenger flight (STS-6), a major aft leak was detected. After considerable controversy over the validity of the readings, a second FRF was conducted that confirmed the severity of the leak. The HGDS readings have, on several other occasions, resulted in a safe launch scrub when excessive leakage in the aft compartment was measured. A second HGDS was added as part of the Return To Flight phase of the Program resulting in different mass spectrometer technologies used as Prime and Back-up HGDS, thus increasing the confidence in this critically important safety system.

During the summer of 1989, two Shuttle missions, STS-35 and 38 were grounded due to hydrogen leaks in the Aft Fuselage and in the 17“ disconnect. The HGDS systems and several portable systems contributed to the resolution of those leakage problems. One of the portable instruments used with great success that summer was a mass spectrometer equipped with a turbo-molecular vacuum pump to allow the analysis of gases primarily composed of helium. This unit was developed into a new permanent system called the Hydrogen Umbilical Mass Spectrometer (HUMS) and was implemented over the 1990 to 1992 time frame. The HUMS provides back-up for the existing combustible gas sensor leak monitors and can be switched to monitor any sample line from the Prime and Back-up HGDS. The development of mass spectrometer technology at KSC over the last 15 years has resulted in decreased hardware costs, greatly increased automation, improved sample system design, and the ability to pump and analyze trace gases in helium backgrounds.

The most recent development in this area has been the design and production of a portable precision helium leak detector to perform main propulsion system helium leak tests for the Orbiter while on the Pad. The Portable Aft Mass Spectrometer (PAMS) is a cart-mounted rebuilt commercial leak detector with new electronics, inlet leak system, and vacuum pumps. The PAMS will detect helium levels of 0.1 ppm in a nitrogen or air background. A key challenge in the development was to establish reliable gas calibration standards near the lower detection limit of the instrument. The extremely high sensitivity is required because the helium leak testing is performed with the Aft air purge operating. These carts are controlled via a laptop computer with graphical user interface and are extremely easy for non-experts to operate and understand. They are also being used for leak testing the Shuttle main engines, prior to installation in the Orbiter (each flow), and are slated to be used for leak testing the Orbital Maneuvering Systems. Use of PAMS has avoided the costly wear and tear on the Prime HGDS and avoided the replacement of a number of instruments in the Main Engine Shop.

TOXIC VAPOR DETECTION

The hyperbolic propellants monomethyihydrazine and nitrogen tetroxide are used in the Space Shuttle Orbital Maneuvering System (OMS), the monopropellant hydrazine is used in the Auxiliary Power System (APU) and many payloads contain hyperbolic propellants. The vapors from these compounds are toxic, and allowable exposures for both hydrazine compounds have recently been lowered to 10 parts per billion (ppb), while nitrogen tetroxide remains at 3 parts per million (ppm). Failure to detect leaks of these compounds can result in injury or death to nearby personnel, as well as costly damage to flight and ground hardware. KSC performs numerous operations per year where monitoring of toxic compounds is required. The Toxic Vapor Detection Laboratory was created to test and qualify commercial instrumentation, and to develop instruments meeting NASA's requirements where commercial equipment does not exist.

In order to meet the requirements to reliably measure 10 ppb hydrazine (N2H4) and monomethylhydrazine (MMH), the Toxic Vapor Detection Laboratory developed an array of instruments. A colorometric dosimeter badge, utilizing two different chemistries, was developed in collaboration with the U. S. Naval Research Laboratory and private industry to indicate individual worker exposure. The degree of saturation of yellow and orange stains indicates the amount of exposure (in ppb-minutes). The use of two color chemistries ensures the reliability of the reading, since there are a few compounds that exist in ambient air at or above 10 ppb which could possibly cause false positive readings from a single color chemistry. The badge not only reliably indicates worker exposure, but it also helps prevent spurious liability claims which might occur as a result of chemical release.

In addition to the dosimeter badges, a portable, direct reading monitor was required. The TVDL developed an improvement to existing electrochemical transducer technology which is now used in a commercially available instrument which can reliably measure 10 ppb. In addition, the laboratory developed an area monitor which can sample multiple locations and operate for months unattended and without maintenance. This instrument has been field tested at both KSC and Air Force payload preparation areas for three months.

The TVDL has emerged as a nationwide leader in the development and implementation of multigas monitors based on Fourier Transform Infrared (FTIR) Spectrometry technology. The laboratory designed and built portable cart-based instruments to monitor the Orbiter Processing Facility high bays for dimethyl ethoxysilane (DMES), the Shuttle tile waterproofing compound. Off-gassing of this compound following application formerly required clearing the high bays of personnel for one or more shifts, since commercial instruments could not distinguish the relatively fast-disappearing toxic compound from longer lived non-toxic compounds. The first prototypes were deployed in only six days from notification of need. The Shuttle launch team estimates savings of over $300,000 annually from these instruments. This same technology was developed into reliable monitors for Space Station ammonia servicing in the Space Station Processing Facility. The instruments feature wide dynamic range, in order to detect both personnel allowable exposure limits (25 ppm) and flammable concentrations (160,000 ppm), as well as built-in alarms and system health checks. In addition, these instruments can reliably measure hydrazines and nitrogen tetroxide at the parts per million level, for leak detection at the launch pad, as well as hydrocarbon contamination of payloads, especially those containing optical components.

ULTRASONIC LEAK DETECTION

Another result of the leaks during the summer of 1989 was the exploration of ultrasonics for leak location. Gas leaks produce sound around 40 kilohertz, somewhat above the human hearing range. Units using parabolic reflectors and contact probes, for listening through vessel walls, were produced. During October, 1992, a leak was detected in the Solid Rocket Booster o-ring seals using a pressure decay test. At the request of the launch team, the Laboratories developed a stereo, contact probe system over a weekend and pin-pointed the leak location through the SRB wall. Several upgrades to these systems have been made and versions which may be used on-board the Shuttle for testing the space suits are in work. While ultrasonic leak detectors are commercially available, KSC systems are much more sensitive and customized versions can be quickly produced to meet a particular need.

HYDROGEN FLAME DETECTION

Commercial fire detectors are generally optimized for detecting hydrocarbon fires. They generally operate by detecting infrared light in the spectral band around 4.2 microns (hot C02 emissions) and sometimes add an ultraviolet (UV) light detector to minimize false alarms. Hydrazine and hydrogen fires emit very weakly in the this IR band but do produce strong UV emissions. Because of this, KSC has spent considerable resources, beginning with the Saturn Program, developing and implementing a system of UV flame detectors to monitor the H2 transfer system at each LC-39 Pad.

The installation of the flare stack in the H2 vent system has led to increased UV flame detector false alarms. The flare stack produces such prodigious quantities of UV irradiance around 200 nm wavelength that, through reflections and Rayleigh scattering, detectors totally shielded from direct radiation by the large LH2 dewer or other structures are activated. A new system near completion of the prototype stage, uses an IR detector, sensitive around the 2.8 micron hot H20 band, and a UV detector, to eliminate false alarms due to the flare stack and other sources. The signals from the UV and IR bands are correlated, eliminating any source that does not simultaneously stimulate both detectors, then high pass filtered to eliminate reflection of the slowly pulsating flare stack fire. Small fires pulsate rapidly in luminosity while the flare stack pulsates slowly. This detector type is also expected to function well for hydrazine fire detection.

During the first launch attempt for STS-12, an on pad abort occurred requiring shut down of the main engines. A hydrogen valve failed to close causing a significant fire. This fire was not visible to ground controllers due the optically thin flame produced by hydrogen and the bright daylight background. An effort was initiated to create a technology for visualizing hydrogen fires for launch controllers. Several approaches were attempted before settling on an approach called Multispectral Television (MTV). This approach involves subtracting IR images made within and just outside the hot H20 emission band, then overlaying that image onto a visible television image. The technology has progressed through several stages of development using differing IR imaging technologies. The current approach using new uncooled lead selenide arrays and KSC developed electronics, holds the promise of low cost hydrogen fire cameras.

TESTING AND DATA ACQUISITION

The Data Acquisition Systems Laboratory focuses on providing new and replacement technologies for gathering, recording and analyzing data that are inexpensive and meet customer needs. Capabilities run from small PC-based data systems using LabView software to large facility systems such as the Permanent Measurements System (PMS). The PMS is an early 1980's system of roughly 800 channels that gathers environmental and special measurements during Shuttle launches.

New technologies have been invented to replace the PMS with a highly flexible and adaptive system that will significantly reduce manpower costs while dramatically improving system capabilities, called the Advanced Data Acquisition System (ADAS). Each transducer, when calibrated, will be mated to a cable pig-tail containing a programmable memory device, called tag-ram, that will contain all of the calibration and other relevant data in a remotely accessible format. When the transducer is installed in the field, a signal conditioner, called a Universal Signal Conditioning Amplifier (USCA), will be attached to the pig-tail. The USCA will automatically read the tag-ram and configure itself in a default configuration according to the tag-ram data. This includes excitation voltage, filtering and up to eighth order linearization (performed real time). This moves the signal conditioner from a facility rack to the proximity of transducer solving numerous noise, grounding, and signal problems. The output of the USCA can be analog or digital to facilitate phase-in of the new PMS. Software, located in the Launch Control Center, called ADAS Command Application (ACA), allows an operator to reconfigure the USCA from a keyboard instead of making hardware changes. The data streams are merged onto a fiber optic data link and transmitted to the LCC where state of the art telemetry equipment will record and provide quick look data output. The recording of data will use Redundant Array of Inexpensive Disks (RAID) system rather than expensive tape recorders. The telemetry system with the RAID recorders has been implemented. The USCA and AUI upgrades are to be complete by the end of fiscal 2001.

The Laboratory also provides a variety of flexible and portable data acquisition systems for users in the Launch Equipment Test Facility, a major mechanical test facility in the KSC Industrial Area, and for temporary use at any location on KSC or the adjoining Cape Canaveral Air Station (CCAS). These systems run the gamut from a 140 channel high speed data acquisition and recording system mounted in a semi-truck trailer to a step van, called the Fast Response Instrumentation Van, which can deploy up to 50 measurements within a few hours. Special tests which have been supported include qualification tests of the major Pad GSE systems (Tail Service Masts, ET Umbilical, GOX Vent Hood, Hold Down Posts), numerous GSE component tests, such as cryogenic control valves and high pressure helium valves, and facility testing including a bridge load test, movement measurements on a buried utility tunnel, special environmental testing during CCAS launches and many others. Customers have included various NASA organizations, the Air Force, and the Naval Ordinance Test Unit. These portable systems have been continually upgraded to reduce response times and accommodate specialized customer needs.

NAVIGATION AND POSITIONING TOOLS

Alignment and positioning during the painstaking operations of installing or mating flight hardware can be critical to maintain build-up tolerances and avoid damage. These operations are also typically manpower intensive with observers stationed at multiple locations, all communicating with a task leader and crane operator. For example, a device was developed to ease the operation of lowering the ET down onto the Solid Rocket Booster (SRB) forward attach points, consisting of lasers that have been embedded into the taper pins used to bring the ET forward attach bolt holes into alignment with those from each SRB. The crane operator, high above the ET, can actually see the laser beams and line the ET up so that the beam shines through the holes and onto the Vehicle Assembly Building ceiling. Also, to assist in ET Aft SRB attachment, the ET Centering Device consists of two ultrasonic transducers, mounted on each SRB, to provide range to the ET skin, and a laser to project a spot on a grid marked on the tank. A hand-held terminal provides the task leader with the range data and thereby the crane movements necessary to center the ET prior to making the aft attachments. Several other similar tools have been developed for payload installations in the Orbiter, both vertical and horizontal and for the alignment of ground support equipment at the Pads.

The Landing Aids Laboratory focuses exclusively on the important problems associated with testing and periodically certifying the runway landing aids ready to support flights. The prime systems that guide the vehicle to touch-down are the Tactical Air Navigation System (TACAN) and the Microwave Scanning Beam Landing System (MSBLS). These systems require hi-annual flight test and certification. The original system for flight testing involved a high powered laser tracker and a test aircraft containing TACAN and MSBLS receivers. The costs, hazards and lack of real time data analysis stimulated replacing this system with one based on the Global Positioning System (GPS). Various versions of the GPS system have been flying since 1988 when the satellite constellation was only partially complete and tests had to be performed at odd hours of the day and night. The current system utilizes state of the art carrier phase positioning and is expected to provide aircraft position accuracy on the order of 10 centimeters in real time. This will, for the first time, support testing of the MSBLS elevation signal accuracy down to the runway. We continue to provide Operations with flight test systems which are smaller, more accurate, easier to use, and meet the many specific requirements for this application.

CLEAN ROOM CONTAMINATION DETECTION

Payloads are processed in controlled clean room environments to protect optical and electromechanical systems from contamination that could affect reliability and performance. The technologies for monitoring clean room quality, with the exception of airborne particle concentration, is labor intensive and involves collection with analysis after the fact. Several approaches for real time monitoring have developed to allow for adequate contamination control. A real time particle fall-out meter was developed that provides a signal proportional to the dust accumulation on a horizontal mirror surface. It’s sensitivity is such that personnel activity is easily detectable over a 24 hour period. This unit allows clean room monitors to respond immediately should rising signals indicate a contamination problem, and it’s small size allows it to be installed next to or even inside a payload. A system is under development that will transmit actual images of the dust particles and perform a size distribution analysis to essentially eliminate the manual sampling and laboratory testing currently performed.

Two important systems were co-developed with Small Business Innovative Research contractors and universities. These developments improved the calibration of optical particle counters and provide a means of real-time determination of non-volatile residue contamination. Current methods of calibrating airborne particle counters (which generally operate by counting and sizing particles that pass through and scatter laser light) are very inadequate, providing what might be considered a health check. A system has been developed that disperses latex microsphere in a laminar column of falling air at a controllable rate. These spheres are of a controlled size distribution and provide a traceable absolute calibration of the counter's output. A Surface Acoustic Wave (SAW) device has been developed that provides real-time indication of non-volatile residue deposition. It could replace the current method which is labor intensive and provides one measurement every two weeks. KSC is also working with a local university on using Langmuir-Blodgett films to provide reliable calibrations of these devices.

NON-DESTRUCTIVE INSPECTION TOOLS

The Space Shuttle fleet is aging and so the requirements for inspection of the many structural and functional parts of the Shuttle are steadily increasing. KSC has developed several specialized instruments to reduce manpower associated with inspection tasks, decrease the overall Shuttle flow time, or provide inspection techniques which were not previously available. These instruments, now in various stages of use, prototype, or production, have demonstrated that instruments for inspection tasks can have significant advantages over manual inspections including documentation of inspection results, decrease in inspection time, unambiguous quantification of problem parameters, and the reduction of dependencies on human expertise.

Current procedures for measuring surface defects or scratches in metal mating surfaces is to make a latex mold impression followed by laboratory measurements and a post repair mold impression to verify corrective action. KSC developed a hand-held device using structured light (a laser line projected oblique to the surface) and a microscope, that allows an operator to quickly measure the depth of a defect by the changing contour of the laser line on a computer/video screen. This system, called Surface Defect Analyzer (SURDA) is being adapted to use on hard to reach surfaces (e.g. SRB nozzle joint groove) and small diameter tubing such as on the Main Engines.

A key inspection for Shuttle safety involves the condition of the forward Shuttle window outer panes. After each launch, the haze is polished off, and using a bright light and magnifier, an inspector lies on a test stand and manually inspects the window. Identified defects are marked on a mylar drawing that serves as the tracking document for that particular window. These inspections are very labor intensive, provide poor documentation, and have missed important defects. If significant defects are found (a depth of approximately one thousandth of an inch) a mold impression is made and measured. An instrument is under development that attaches to the window cover mounting points and automatically scans the window identifying the location of any defects. The system maintains a software map of that particular piece of glass and can identify any new defects. The operator can then use a feature called a refocus microscope to return to the identified defect sites and measure the dimensions of the defect. The existing inventory of windows is currently being scanned after each flight using a prototype Automatic Window Inspection Device (AWID). The first production model will be completed this year.

Other key inspection tools in work include using pulsed light and an infrared camera to identify areas of aluminum corrosion under the coated surface for inspecting structural members of the Orbiter, a commercially available Laser Shearography device for identifying debonds in Spray On Foam Insulation (SOFI) on the External Tank and KNA cork insulation on the SRB'S, and a mapping system to provide video maps of small defects in the Orbiter Reinforced Carbon-Carbon materials (nose cap and wing leading edges). This is a key area for future instrumentation as new physical techniques and detectors can be brought to bear on the problems associated with the aging of the Shuttle fleet.

TECHNOLOGY TRANSFER

An increased emphasis is being placed on the transfer of NASA technologies to the commercial sector to create jobs and improve international competitiveness. The instrumentation area is the strongest contributor of commercially viable new technologies at KSC. Four of the existing eight Cooperative agreements involve inventions that originated in the Instrumentation Laboratories and two more instrumentation agreements in the offering phase. Of the 63 New Technology Reports submitted to NASA by I-NET since contract inception, over 75% originated in the Instrumentation Laboratories. Inventions with commercial partners include the USCA/ADAS, the UV/IR Flame Detectors, and the software for FTIR Spectrometers. Several others are about to be offered or are being negotiated.

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