



# TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

-  **Technology Focus**
-  **Electronics/Computers**
-  **Software**
-  **Materials**
-  **Mechanics/Machinery**
-  **Manufacturing**
-  **Bio-Medical**
-  **Physical Sciences**
-  **Information Sciences**
-  **Books and Reports**



## INTRODUCTION

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### **Optical Comb From a Whispering Gallery Mode Resonator for Spectroscopy and Astronomy Instruments Calibration**

**This technology can be used for surveillance of the Earth from space.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

The most accurate astronomical data is available from space-based observations that are not impeded by the Earth's atmosphere. Such measurements may require spectral samples taken as long as decades apart, with the 1 cm/s velocity precision integrated over a broad wavelength range. This raises the requirements specifically for instruments used in astrophysics research missions — their stringent wavelength resolution and accuracy must be maintained over years and possibly decades. Therefore, a stable and broadband optical calibration technique compatible with spaceflights becomes essential. The space-based spectroscopic instruments need to be calibrated *in situ*, which puts forth specific requirements to the calibration sources, mainly concerned with their mass, power consumption, and reliability.

A high-precision, high-resolution reference wavelength comb source for astronomical and astrophysics spectroscopic observations has been developed that is deployable in space. The optical comb will be used for wavelength calibrations of spectrographs and will enable Doppler measurements to better than 10 cm/s precision, one hundred times better than the current state-of-the-art.

The concept leverages the progress of wide-span frequency comb generation in frequency standards and metrology. The source consists of a crystalline whispering gallery mode (WGM) microresonator, a near-IR tunable single-frequency CW (continuous wave) laser, an FM (frequency modulated) spectroscopy unit, and control and stabilization electronics. The coupling in and out of the resonator is fiber-based

through the evanescent waves. This approach is based on an external laser coupled to the Kerr-media WGM resonator.

This novel precision comb provides a new generation of super-stable, evenly spaced, and wideband wavelength calibration sources. In addition, this source does not age as the lamps do. Presently, this approach allows users to achieve an absolute accuracy of better than  $10^{-12}$  per day when referenced to a suitable atomic transition.

The improved Doppler measurement accuracy and resolution will significantly enhance the current astronomy observation capability in exoplanet search and the study of cosmology dynamics.

*This work was done by Dmitry V. Strelkov, Nan Yu, and Robert J. Thompson of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-48135*

### **Real-Time Flight Envelope Monitoring System**

**The system uses a combination of three separate detection algorithms to provide a warning at a preset number of degrees prior to stall.**

*Dryden Flight Research Center, Edwards, California*

The objective of this effort was to show that real-time aircraft control-surface hinge-moment information could be used to provide a robust and reliable prediction of vehicle performance and control authority degradation. For a given airfoil section with a control surface — be it a wing with an aileron, rudder, or elevator — the control-surface hinge moment is sensitive to the aerodynamic characteristics of the section. As a result, changes in the aerodynamics of the section due to angle-of-attack or environmental effects such as icing, heavy rain, surface contaminants, bird strikes, or battle damage will affect the control surface hinge moment. These changes include both the magnitude of the hinge moment and its sign in a

time-averaged sense, and the variation of the hinge moment with time. The current program attempts to take the real-time hinge moment information from the aircraft control surfaces and develop a system to predict aircraft envelope boundaries across a range of conditions, alerting the flight crew to reductions in aircraft controllability and flight boundaries.

The concept was tested across a wide range of conditions and observed in-flight contamination, and a system and methodology of using the hinge-moment information to predict sectional airfoil stall in the presence of these contaminants was developed. An experimental test program was designed to provide the broadest test of the hinge

moment monitoring concept. A NACA 3415 airfoil section with a 25-percent chord flap was tested with a series of simulated aerodynamic contaminants. These contaminants were designed to provide a range of simulated environmental and structural hazards, which would produce varying degrees of performance degradation, primarily in the form of premature stall and loss of maximum lift. These simulated cases included both leading-edge glaze and rime ice, both moderate and severe leading-edge roughness, and both a simulated 3D leading-edge and a simulated upper surface damage case.

Data from the experimental tests were used to develop a stall prediction methodology and detection algorithm

based on the unsteady hinge moment results. The stall detection algorithm provided a warning of stall several degrees prior to actual stall. In this way, the envelope monitoring system can alert the flight crew to the current aircraft envelope boundaries for both longitudinal and lateral control.

The system uses a combination of three separate detection algorithms based on the unsteady hinge moment signal to provide a warning at a preset number of degrees prior to stall. Results from the three algorithms are averaged

to provide a single warning prediction. The averaging of the three separate algorithms provides a level of redundancy in the calculation and can also be used as a measure of the confidence of the stall boundary warning prediction. For the majority of the cases, the detection algorithm produced a warning within  $\pm 0.7^\circ$  of the set boundary value. There appears to be sufficient signal to provide a stall warning boundary out to approximately  $4^\circ$  prior to stall. Output from the detector function for the range of shown contaminations collapses onto a single

curve, as a function of the angle-of-attack prior to stall. By collapsing onto a single curve, the developed detector function-based system can use a simple threshold approach to set a variable warning boundary, up to several degrees prior to stall.

*This work was done by Michael Kerho of Rolling Hills Research Corp. and Michael B. Bragg and Phillip J. Ansell of the University of Illinois at Urbana-Champaign for Dryden Flight Research Center. Further information is contained in a TSP (see page 1). DRC-010-014*

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## Nemesis Autonomous Test System

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A generalized framework has been developed for systems validation that can be applied to both traditional and autonomous systems. The framework consists of an automated test case generation and execution system called Nemesis that rapidly and thoroughly identifies flaws or vulnerabilities within a system. By applying genetic optimization and goal-seeking algorithms on the test equipment side, a "war game" is conducted between a system and its complementary nemesis. The end result of the war games is a col-

lection of scenarios that reveals any undesirable behaviors of the system under test.

The software provides a reusable framework to evolve test scenarios using genetic algorithms using an operation model of the system under test. It can automatically generate and execute test cases that reveal flaws in behaviorally complex systems. Genetic algorithms focus the exploration of tests on the set of test cases that most effectively reveals the flaws and vulnerabilities of the system under test. It leverages advances in state-

and model-based engineering, which are essential in defining the behavior of autonomous systems. It also uses goal networks to describe test scenarios.

*This work was done by Kevin J. Bartrop, Cinyoung Lee, Gregory A. Horvath, and Bradley J. Clement of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at [danielb@caltech.edu](mailto:danielb@caltech.edu). Refer to NPO-47596.*

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## Mirror Metrology Using Nano-Probe Supports

**Any application requiring precise measurement of a flexible object could benefit from this invention.**

*Goddard Space Flight Center, Greenbelt, Maryland*

Thin, lightweight mirrors are needed for future x-ray space telescopes in order to increase x-ray collecting area while maintaining a reduced mass and volume capable of being launched on existing rockets. However, it is very difficult to determine the undistorted shape of such thin mirrors because the mounting of the mirror during measurement causes distortion. Traditional kinematic mounts have insufficient supports to control the distortion to measurable levels and prevent the mirror from vibrating during measurement. Over-constrained mounts (non-kinematic) result in an unknown force state causing mirror distortion that cannot be determined or analytically removed. In order to measure flexible mirrors, it

is necessary to over-constrain the mirror. Over-constraint causes unknown distortions to be applied to the mirror. Even if a kinematic constraint system can be used, necessary imperfections in the kinematic assumption can lead to an unknown force state capable of distorting the mirror. Previously, thicker, stiffer, and heavier mirrors were used to achieve low optical figure distortion. These mirrors could be measured to an acceptable level of precision using traditional kinematic mounts. As lighter weight precision optics have developed, systems such as the whiffle tree or hydraulic supports have been used to provide additional mounting supports while maintaining the kinematic assumption.

The purpose of this invention is to over-constrain a mirror for optical measurement without causing unacceptable or unknown distortions. The invention uses force gauges capable of measuring 1/10,000 of a Newton attached to nano-actuators to support a thin x-ray optic with known and controlled forces to allow for figure measurement and knowledge of the undeformed mirror figure. The mirror is hung from strings such that it is minimally distorted and in a known force state. However, the hanging mirror cannot be measured because it is both swinging and vibrating. In order to stabilize the mirror for measurement, nano-probes support the mirror, causing the mirror to be over-constrained.

A closed-loop software algorithm is used to control the forces applied by the nano-probes. These support forces are determined by finite element analysis (FEA) to have an acceptable and known effect on the mirror distortion. If necessary, distortions created by the nano-probes can later be analytically removed based on the correlated FEA.

The mirror is hung from strings in the suspension metrology mount (SMM) fixture. Nano-probes mounted to the fixture in optimized locations extend to

stabilize the mirror. The software closed-loop force control algorithm is run to adjust the forces to pre-determined levels. Once stabilized and in a known force configuration, the mirror is measured with an interferometer.

The novel feature of this invention is the ability to measure and control the forces supporting an object whose shape must be precisely known. The advantage of this invention over prior art in the field is that a flexible object may be over-constrained without causing unknown

distortions. Also, imperfections in kinematic type mounts can be measured and controlled. Using this invention, mirrors have been measured and their figures have been correlated with the figures predicted by FEA.

*This work was done by David Robinson, Maoling Hong, and Glenn Byron of Goddard Space Flight Center; Ryan McClelland of SGT, Inc.; and Kai-Wing Chan of the University of Maryland. Further information is contained in a TSP (see page 1). GSC-16084-1*

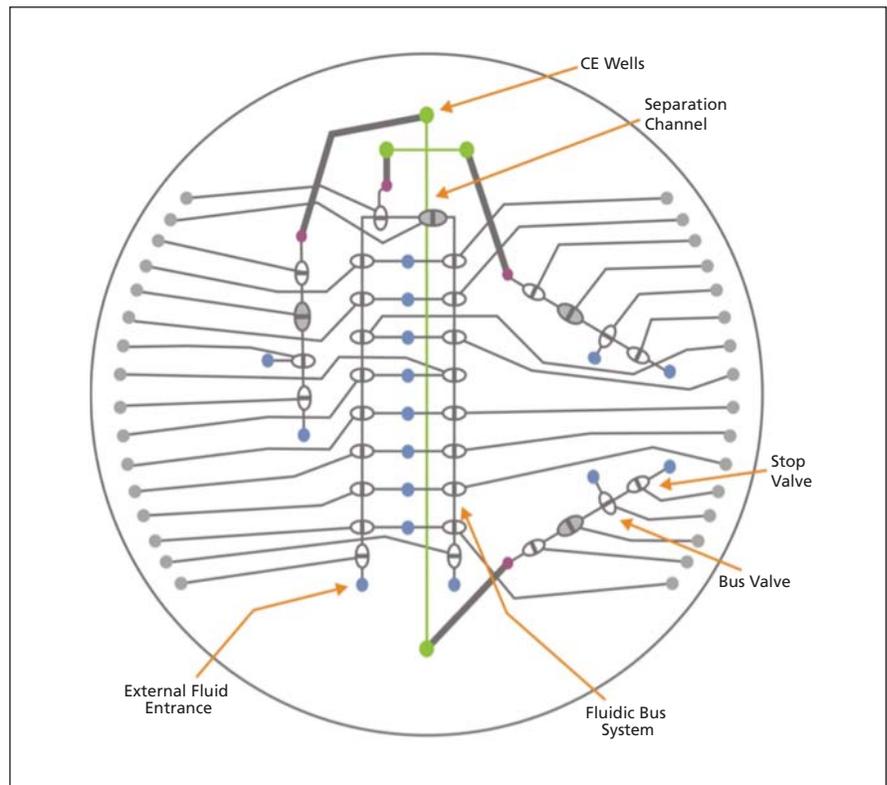
## Automated Lab-on-a-Chip Electrophoresis System

**Robotic analysis in defense or security operations that require sample handling or dilution can utilize this technology.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Capillary electrophoresis is an analytical technique that can be used to detect and quantify extremely small amounts of various biological molecules. In the search for biochemical traces of life on other planets, part of this search involves an examination of amino acids, which are the building blocks of life on Earth. The most sensitive method for detecting amino acids is the use of laser induced fluorescence. However, since amino acids do not, in general, fluoresce, they first must be reacted with a fluorescent dye label prior to analysis. After this process is completed, the liquid sample then must be transported into the electrophoresis system. If the system is to be reused multiple times, samples must be added and removed each time. In typical laboratories, this process is performed manually by skilled human operators using standard laboratory equipment. This level of human intervention is not possible if this technology is to be implemented on extraterrestrial targets.

A multi-layer glass wafer device was designed that is capable of performing all necessary steps of the analysis. The device consists of bonded layers of Borofloat glass wafers and a flexible polydimethylsiloxane (PDMS) membrane (254- $\mu\text{m}$  thick). This flexible polymeric material was used to open and close liquid junctions in order to perform valving operations. At the base of the stack, a microfluidic channel (20 $\times$ 50  $\mu\text{m}$  cross-section) was used for electrophoretic separations and a 405-nm laser was employed for fluorescence detection at the end of the channel.



Shown here is the **Layout of a Chemistry "Circuit"** designed for the purpose of performing automated analyses of amino acids. Experiments have been performed in which a sample of amino acids is placed on the surface of a chip. All subsequent sample handling processes are performed by the microfluidic circuit shown here.

Microchip capillary electrophoresis (CE) combined with laser induced fluorescence detection (LIF) was selected as an extremely sensitive method to detect amino acids and other compounds that can be tagged with a fluorescent dye. It is highly desirable to package this technology into an integrated, autonomous,

*in situ* instrument capable of performing CE-LIF on the surface of an extraterrestrial body. However, to be fully autonomous, the CE device must be able to perform a large number of sample preparation and analysis operations without the direct intervention of a human. While some of this functionality

— in particular, the routing of samples and other liquids on chip — has been demonstrated previously, the vast majority of the steps required for CE must still be done by laboratory researchers who manually perform the necessary activities off chip. This work represents the demonstration of a fully automated end-to-end CE-LIF analysis.

All of the critical functions of a future *in situ* instrument including mixing, dilution, derivatization, and separation of samples have been successfully performed on a chip. This technology and the experimental protocols developed to use it will be the heart of any future lab-on-a-chip based instruments for *in situ* life detection on the surface of a ex-

traterrestrial body, but can be readily adapted to a number of biological and defense applications.

*This work was done by Peter A. Willis, Maria Mora, Harold F. Greer, and Anita M. Fisher of Caltech and Sherrisse Bryant of Louisiana State University for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47888*

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## Techniques for Down-Sampling a Measured Surface Height Map for Model Validation

*NASA's Jet Propulsion Laboratory, Pasadena, California*

This software allows one to down-sample a measured surface map for model validation, not only without introducing any re-sampling errors, but also eliminating the existing measurement noise and measurement errors.

At present, the surface map of an optic is measured using an interferometric instrument such as a Zygo interferometer. In such a case, the measured surface map has a high resolution and needs to be down-sampled before using it in model validation software. The software tool of the current two new techniques can be used in all optical model validation processes involving large space optical surfaces.

Down-sampling of a surface map is accomplished by using the analytical ex-

pressions of Zernike-polynomials of the given surface map for a low-spatial frequency component and the spectrum or the power spectral density (PSD) data of the given surface map for mid-spatial frequency component. The challenge is to decrease the matrix size of a measured optical surface height map to match it with a model validation software tool.

During the down-sampling of a surface map, this software tool preserves the low-spatial frequency characteristic of a given surface map through the use of Zernike polynomial fit coefficients, and maintains mid-spatial frequency characteristics of the given surface map by the use of the spectrum or the PSD data of the given surface map calculated

from the mid- and the high-spatial frequency components of the original surface map.

These new methods do not introduce any aliasing and interpolation errors as is done by the conventional interpolation and FFT-based spatial-filtering method. Also, they automatically eliminate the measurement noise and other measurement errors such as artificial discontinuity.

*This work was done by Erkin Sidick of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This software is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at danielb@caltech.edu. Refer to NPO-47711.*

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## Multi-Component, Multi-Point Interferometric Rayleigh/Mie Doppler Velocimeter

*Langley Research Center, Hampton, Virginia*

An interferometric Rayleigh scattering system was developed to enable the measurement of multiple, orthogonal velocity components at several points within very-high-speed or high-temperature flows. The velocity of a gaseous flow can be optically measured by sending laser light into the gas flow, and then measuring the scattered light signal that is returned from matter within the flow. Scattering can arise from either gas molecules within the flow itself, known as Rayleigh scattering, or from particles within the flow, known as Mie scattering. Measuring Mie scattering is the basis of all commercial laser Doppler and particle imaging velocimetry systems, but particle seeding

is problematic when measuring high-speed and high-temperature flows.

The velocimeter is designed to measure the Doppler shift from only Rayleigh scattering, and does not require, but can also measure, particles within the flow. The system combines a direct-view, large-optic interferometric setup that calculates the Doppler shift from fringe patterns collected with a digital camera, and a subsystem to capture and re-circulate scattered light to maximize signal density. By measuring two orthogonal components of the velocity at multiple positions in the flow volume, the accuracy and usefulness of the flow measurement increase significantly over single or non-

orthogonal component approaches.

The subject architecture can be combined with CARS (coherent anti-Stokes Raman spectroscopy) to provide temperature and composition of the measured flow. The system is also capable of characterizing high-velocity flames, up to 2,400 K, which is useful in analyzing high-speed combustion in fighter jet engines, scramjet engines, and even potentially in gas turbines.

*This work was done by Paul M. Danehy and Joseph W. Lee of Langley Research Center and Daniel Bivolaru of The George Washington University — Hampton, VA. Further information is contained in a TSP (see page 1). LAR-17235-1*



### **Frequency to Voltage Converter Analog Front-End Prototype**

**The device compares multiple filter circuits side-by-side.**

*John F. Kennedy Space Center, Florida*

The frequency to voltage converter analog front end evaluation prototype (F2V AFE) is an evaluation board designed for comparison of different methods of accurately extracting the frequency of a sinusoidal input signal. A configurable input stage is routed to one or several of five separate, configurable filtering circuits, and then to a configurable output stage. Amplifier selection and gain, filter corner frequencies, and comparator hysteresis and voltage reference are all easily configurable through the use of jumpers and potentiometers.

Certain types of liquid and gas flow measurement devices utilize a turbine and magnetic sensor to output a sinusoidal signal with a frequency proportional to the rate of flow through the turbine. In order to interface with the Command and Control infrastructure at Kennedy Space Center (KSC), this sinusoidal frequency must be converted into an analog voltage level proportional to the frequency. Existing commercial off-the-shelf (COTS) signal conditioners designed for this task are either obsolete or unqualified for use at KSC. In order to design a replacement signal conditioner that will meet the environmental and operational requirements for use at

KSC, an accurate and reliable analog circuit must be designed to convert the input sine wave into a square wave of the same frequency, while eliminating inaccuracies due to ambient temperature, electromagnetic interference (EMI), and varying signal amplitudes from the turbine sensor. The F2V AFE evaluation board allows side-by-side comparison of several circuit designs to help determine which is optimal.

The F2V AFE evaluation board consists of eight main sections: power, input stage, output stage and five separate, parallel filtering and amplification stages. The power stage accepts external 5 VDC power and generates a -5 VDC supply from this. Both supplies are routed to the other circuit stages. The input stage takes the input sinusoidal signal and passes it through an optional gain amplifier to a header where it can be routed to one or several of the five filter topologies. The output stage contains a header that can be used to select the output of one of the five filters for conversion to a square wave. The five filter topologies represent different methods for amplifying and filtering the input signal. This evaluation board provides a wide array of options for determining the optimal configuration for accurately extracting the

frequency of a sine wave varying in amplitude from 10 mV to >1 V, and in frequency from 20 Hz to 2.5 kHz.

This device is intended to be an evaluation platform for determining an optimum frequency detection circuit design. An evaluation platform benefiting from the constrained routing and component size and placement of surface-mount design, and containing the actual components that will be used in the final design, has many benefits over older breadboard prototyping techniques, where parasitic inductances and capacitance may have a significant effect on test circuits. This device is useful for situations where multiple design options must be compared before a circuit is selected for a final production design. The evaluation board is designed to accurately detect signals from 10 mV peak up to 5 V peak, and frequencies from 20 Hz to 3 kHz, but component substitution will allow both the frequency and voltage range to be significantly expanded or contracted. Other input waveforms, including square waves, can also be processed.

*This work was done by Carlos Mata and Matthew Raines of ASRC Aerospace Corp. for Kennedy Space Center. Further information is contained in a TSP (see page 1). KSC-13582*

### **Dust-Tolerant Intelligent Electrical Connection System**

**This technology has application in aerospace, military, homeland security, mining, and oil and gas exploration operations that are conducted in uncontrolled environments.**

*John F. Kennedy Space Center, Florida*

Faults in wiring systems are a serious concern for the aerospace and aeronautic (commercial, military, and civilian) industries. Circuit failures and vehicle accidents have occurred and have been attributed to faulty wiring created by open and/or short circuits. Often, such circuit failures occur due to vibration during vehicle launch or operation. Therefore, developing non-intrusive fault-tolerant techniques is necessary to

detect circuit faults and automatically route signals through alternate recovery paths while the vehicle or lunar surface systems equipment is in operation. Electrical connector concepts combining dust mitigation strategies and cable diagnostic technologies have significant application for lunar and Martian surface systems, as well as for dusty terrestrial applications.

By creating intelligent electrical con-

nectors that detect, identify, and locate circuit faults and that then bypass damaged conductors and route to available spares, the detection of connector failures is improved, and it becomes possible to recover from mission-threatening circuit faults and failures. Three styles of electrical connector concepts for use in zero-gravity and reduced-gravity dusty environments were developed: conventional connector systems with protective

dust barriers, contactless connector systems, and smooth connector systems. The conventional connector with protective dust barrier mitigates dust by incorporating a physical dust shield. These dust barriers may be retrofitted to existing military or International Space Station connectors. Alternatively, it is possible to utilize existing connectors that can be incorporated into a universal connector housing. Contactless connectors have advantages over conventional connectors where environment integrity poses a design constraint.

The dust-tolerant intelligent electrical connection system has several novel concepts and unique features. It combines intelligent cable diagnostics (health monitoring) and automatic circuit routing capabilities into a dust-tolerant electrical

umbilical. It retrofits a clamshell protective dust cover to an existing connector for reduced gravity operation, and features a universal connector housing with three styles of dust protection: inverted cap, rotating cap, and clamshell. It uses a self-healing membrane as a dust barrier for electrical connectors where required, while also combining lotus leaf technology for applications where a dust-resistant coating providing low surface tension is needed to mitigate Van der Waals forces, thereby disallowing dust particle adhesion to connector surfaces. It also permits using a ruggedized iris mechanism with an embedded electrodynamic dust shield as a dust barrier for electrical connectors where required.

The system also can use a coating to repel lunar dust and self-clean the sur-

face, and incorporates cable health monitoring and automatic routing capabilities into an inductively coupled or capacitively coupled contactless electrical connector. An innovative knob and donut type connector is also included to mitigate lunar dust challenges. Adding electrodynamic dust shields is also possible where needed to combine active dust mitigation with EMI (electromagnetic interference) shielding capability.

*This work was done by Mark Lewis, Adam Dokos, Jose Perotti, Carlos Calle, and Robert Mueller of Kennedy Space Center; and Gary Bastin, Jeffrey Carlson, Ivan Townsend III, Christopher Immer, and Pedro Medelius of ASRC Aerospace Corporation. For more information, contact the Kennedy Space Center Innovative Partnerships Office at (321) 867-5033. KSC-13578*

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## Gigabit Ethernet Asynchronous Clock Compensation FIFO

*Lyndon B. Johnson Space Center, Houston, Texas*

Clock compensation for Gigabit Ethernet is necessary because the clock recovered from the 1.25 Gb/s serial data stream has the potential to be 200 ppm slower or faster than the system clock. The serial data is converted to 10-bit parallel data at a 125 MHz rate on a clock recovered from the serial data stream. This recovered data needs to be processed by a system clock that is also running at a nominal rate of 125 MHz, but not synchronous to the recovered clock. To cross clock domains, an asynchronous FIFO (first-in-first-out) is used, with the write pointer (wptr) in the recovered clock domain and the read pointer (rptr) in the system clock domain. Because the clocks are generated

from separate sources, there is potential for FIFO overflow or underflow.

Clock compensation in Gigabit Ethernet is possible by taking advantage of the protocol data stream features. There are two distinct data streams that occur in Gigabit Ethernet where identical data is transmitted for a period of time. The first is configuration, which happens during auto-negotiation. The second is idle, which occurs at the end of auto-negotiation and between every packet. The identical data in the FIFO can be repeated by decrementing the read pointer, thus compensating for a FIFO that is draining too fast. The identical data in the FIFO can also be skipped by incrementing the read

pointer, which compensates for a FIFO draining too slowly. The unique and novel features of this FIFO are that it works in both the idle stream and the configuration streams. The increment or decrement of the read pointer is different in the idle and compensation streams to preserve disparity. Another unique feature is that the read pointer to write pointer difference range changes between compensation and idle to minimize FIFO latency during packet transmission.

*This work was done by Jeff Duhachek of Honeywell Aerospace for Johnson Space Center. For further information, contact the JSC Innovation Partnerships Office at (281) 483-3809. MSC-24853-1*

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## High-Speed, Multi-Channel Serial ADC LVDS Interface for Xilinx Virtex-5 FPGA

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Analog-to-digital converters (ADCs) are used in scientific and communications instruments on all spacecraft. As data rates get higher, and as the transition is made from parallel ADC designs to high-speed, serial, low-voltage differential signaling (LVDS) designs, the need will arise to interface these in field-programmable gate arrays (FPGAs). As

Xilinx has released the radiation-hardened version of the Virtex-5, this will likely be used in future missions.

High-speed serial ADCs send data at very high rates. A de-serializer instantiated in the fabric of the FPGA could not keep up with these high data rates. The Virtex-5 contains primitives designed specifically for high-speed, source-syn-

chronous de-serialization, but as supported by Xilinx, can only support bit-widths of 10. Supporting bit-widths of 12 or more requires the use of the primitives in an undocumented configuration, a non-trivial task.

De-serializing the bits from high-speed ADCs running at speeds of 50 Msps or more becomes a non-trivial

problem in the Xilinx Virtex-5. The bit clock speeds are very high (300 MHz or more), and the ADC sample width can be wider than what the built-in Virtex-5 `ISERDES_NODELAY` primitives officially support (12 bits or more). The Virtex-5 User Guide does not specify how to configure the `ISERDES_NODELAY` primitives for such higher bit-widths.

A new SystemVerilog design was written that is simpler and uses fewer hardware resources than the reference design described in Xilinx Application Note XAPP866. It has been shown to work in a Xilinx XC5VSX24OT connected to a MAXIM MAX1438 12-bit ADC using a 50-MHz sample clock. The design can be replicated in the FPGA for

multiple ADCs (four instantiations were used for a total of 28 channels).

*This work was done by Gregory H. Taylor of Caltech for NASA's Jet Propulsion Laboratory. The software used in this innovation is available for commercial licensing. Please contact Daniel Broderick of the California Institute of Technology at [danielb@caltech.edu](mailto:danielb@caltech.edu). Refer to NPO-48191.*





## Glovebox for GeoLab Subsystem in HDU1-PEM

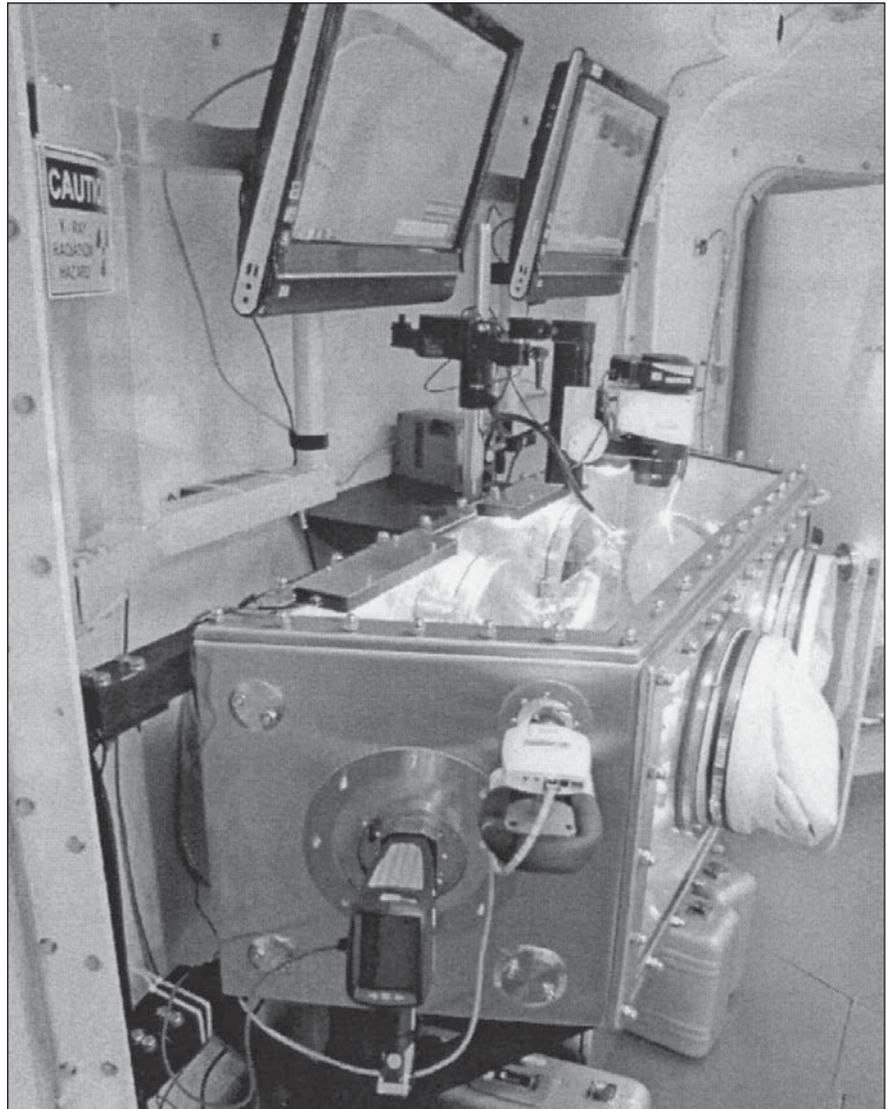
The semiconductor, biotechnology, and nuclear industries may have potential use for these gloveboxes.

*Lyndon B. Johnson Space Center, Houston, Texas*

The GeoLab glovebox was designed to enable the preliminary examination, by astronauts, of geological samples collected from the surface of another planetary body. The collected information would then aid scientists in making decisions about sample curation and prioritization for return to Earth for study. This innovation was designed around a positive-pressure-enriched nitrogen environment glovebox to reduce sample handling contamination. The structure was custom-designed to fit in section H of NASA's Habitat Demonstration Unit 1 Pressurized Excursion Module (HDU1-PEM). In addition, the glovebox was designed to host analytical instruments in a way that prevents sample contamination.

The trapezoidal-shaped design follows the HDU1-PEM structural rib design, and incorporates 304 stainless steel, Viton seals, and clear polycarbonate materials that are known to possess low off-gassing and particle shedding properties. Two 10-in. ( $\approx 25$ -cm) glove ports were installed in the front polycarbonate window with long-sleeved, 32-in. ( $\approx 81$ -cm) Hypalon gloves. The ports allow for full movement inside the glovebox, and can accommodate varying heights of crewmembers. There are clear polycarbonate top and front viewing windows, as well as three 10-in. ( $\approx 25$ -cm) diameter, vacuum-rated, pass-through antechambers to transfer samples from the outside EVA porch area directly into the glovebox. A total of 18 glovebox ports, with varying diameters, were incorporated into the design to accommodate the need for reconfiguration of analytical instrumentation and sensors during different test scenarios. The gloveport design takes into account natural human eye/hand coordination. State-of-the-art environmental monitoring sensors, that can be remotely viewed by computers on the HDU1-PEM avionics networks, are included.

The glovebox design allows for containing and manipulating geological samples that are collected during traverses. The top of the glovebox was designed to be the main viewing window,



The GeoLab Glovebox installed in section H of the HDU1-PEM.

and is constructed with low-profile Waldmann Flat LED lighting for enhanced sample viewing. The high-visibility polycarbonate also allows cameras and microscopes to clearly view samples and inside glovebox work while remaining outside of the clean main chamber. The three 10-in. ( $\approx 25$ -cm) diameter pass-through antechambers function as small, redundant airlocks to transfer samples from outside the habitat directly

into the glovebox to reduce the risk of sample cross-contamination inside the habitat environment. Each antechamber is also equipped with a 17-in. ( $\approx 43$ -cm) long sliding stainless steel tray for sample transfers.

*This work was done by Cynthia Evans of Johnson Space Center, and Michael J. Calaway and Mary Bell of Jacobs Technology. Further information is contained in a TSP (see page 1). MSC-25080-1*

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## Modified Process Reduces Porosity When Soldering in Reduced Gravity Environments

*Lyndon B. Johnson Space Center, Houston, Texas*

A modified process yields lower levels of internal porosity for solder joints produced in reduced-gravity environments. The process incorporates both alternative materials and a modified procedure. The process provides the necessary cleaning action to enable effective bonding of the applied solder alloy with the materials to be joined.

The modified process incorporates a commercially available liquid flux that is applied to the solder joint before heating with the soldering iron. It is subsequently

heated with the soldering iron to activate the cleaning action of the flux and to evaporate most of the flux, followed by application of solder alloy in the form of commercially available solid solder wire (containing no flux). Continued heating ensures adequate flow of the solder alloy around and onto the materials to be joined. The final step is withdrawal of the soldering iron to allow alloy solidification and cooling of the solder joint.

This method provides adequate cleaning of contaminants by the flux agent

from the materials to be joined, but allows dissipation of most of the flux agent prior to application of the solder alloy. This significantly reduces the amount of flux that can be entrapped in the solder alloy that would result in internal porosity.

*This work was done by Kevin Watson of Johnson Space Center; Peter Struk of Glenn Research Center; and Richard Pettegrew, Robert Downs, and Daniel Haylett of the National Center for Microgravity Research. Further information is contained in a TSP (see page 1). MSC-24023-1*



## Use of Functionalized Carbon Nanotubes for Covalent Attachment of Nanotubes to Silicon

**This method enables the introduction of carbon nanotubes onto all types of silicon-based devices and silicon surfaces.**

*Lyndon B. Johnson Space Center, Houston, Texas*

The purpose of the invention is to covalently attach functionalized carbon nanotubes to silicon. This step allows for the introduction of carbon nanotubes onto all manner of silicon surfaces, and thereby introduction of carbon nanotubes covalently into silicon-based devices, onto silicon particles, and onto silicon surfaces.

Single-walled carbon nanotubes (SWNTs) dispersed as individuals in surfactant were functionalized. The nanotube was first treated with 4-t-butylbenzenediazonium tetrafluoroborate to give increased solubility to the carbon nanotube; the second group attached to the sidewall of the nanotube has a silyl-protected terminal alkyne that is de-protected *in situ*. This gives a soluble carbon nanotube that has functional groups appended to the sidewall that can be attached covalently to silicon. This reaction was monitored by UV/vis/NJR to assure direct covalent functionalization.

Once the reaction to form the appropriately functionalized carbon nanotube was complete, the nanotube solution was passed through a plug of glass wool to

remove particulates. This filtered solution was then flocced by diluting with acetone, and filtered through a Teflon membrane. The collected solid was dispersed in dimethylformamide (DMF) with sonication and filtered once again through a Teflon membrane. The functionalized material was then dispersed in dry DMF and assembled onto silicon by hydrosilation. The assembly was conducted by treating the nanotube solution with a catalytic amount of triphenylcarbonium tetrafluoroborate and submersing a hydrogen-passivated silicon sample in the solution. The assembly mixture was agitated with warming for 12 hours. After that time, the silicon sample was rinsed with organic solvent and dried with a stream of nitrogen. The assembly was characterized by AFM (atomic force microscopy).

The most immediate and obvious use of this procedure is the covalent attachment of carbon nanotubes onto silicon. This method allows for the attachment of individual (not bundles) carbon nanotubes. With this methodology, the highest temperature required to regen-

erate the pristine carbon nanotube is 450 °C.

Although other methods exist to introduce carbon nanotubes into silicon-based devices, this methodology is selective for silicon and allows for the generation of working devices at a much lower temperature.

*This work was done by James M. Tour, Christopher A. Dyke, Francisco Maya, Michael P. Stewart, Bo Chen, and Austen K. Flatt of Rice University for Johnson Space Center. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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*Refer to MSC-24068-1, volume and number of this NASA Tech Briefs issue, and the page number.*

## Flexible Plug Repair for Shuttle Wing Leading Edge

**Thin, flexible plugs conform to surfaces.**

*Lyndon B. Johnson Space Center, Houston, Texas*

In response to the Columbia Accident Investigation Board report, a plug repair kit has been developed to enable astronauts to repair the space shuttle's wing leading edge (WLE) during orbit. The plug repair kit consists of several 17.78-cm-diameter carbon/silicon carbide (C/SiC) cover plates of various curvatures that can be attached to the refractory carbon-carbon WLE panels using a TZM refractory metal attach mechanism. The attach mechanism is inserted

through the damage in the WLE panel and, as it is tightened, the cover plate flexes to conform to the curvature of the WLE panel within 0.050 mm. An astronaut installs the repair during an extravehicular activity (EVA). After installing the plug repair, edge gaps are checked and the perimeter of the repair is sealed using a proprietary material, developed to fill cracks and small holes in the WLE.

In developing the plug repair concept, several issues had to be addressed

including material, design, performance, and operability. An oxyacetylene torch was calibrated to heat a specimen to WLE entry temperatures and was used to screen candidate repair materials. Promising materials were then tested in the Johnson Space Center arc-jet test facility to determine their resistance to oxidation in a hypersonic environment. C/SiC was selected as the cover plate material because of its superior strength and resistance to oxida-

tion. In order to raise its operational temperature limit, a proprietary oxidation barrier coating was developed. TZM was selected as the attach mechanism material because of its manufacturability and structural performance as well as its ability to withstand the plasma environment when coated with the oxidation barrier coating.

Prior art involved square, inflexible plugs that were too small to provide complete WLE coverage and would also create protuberances into the hypersonic flow that would overheat during operation. This innovation is an evolution of the prior art in that the current

plug is a thin, flexible double-curved shell with rounded edges, which facilitates a deformed shape that conforms to the WLE geometry with minimal disturbance of the flow.

The repair plug is designed to capitalize on flexibility and curved shape in order to minimize the number of cover plates required. The current design reduced the number of unique plug shapes required to cover critical WLE regions from over 1,300 to less than 20. Non-linear finite element analysis, including contacting surfaces, was used to model the plug during installation and operation. Computa-

tional fluid dynamics and thermal analysis were used to predict plug temperatures during entry.

*This work was done by Charles J. Camarda, Joseph Sikora, Russel Smith, H. Rivers, and Stephen J. Scotti of NASA; Alan M. Fuller of United Space Alliance; Robert Klacka of General Electric Ceramic Composites, LLC; Martin Reinders of The Boeing Company; Francis Schwind of Carbon-Carbon Advanced Technologies, Inc.; Brian Sullivan of Materials Research and Design, Inc.; and Dean Lester of ATK Thiokol for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24347-1*

## Three Dimensionally Interlinked, Dense, Solid Form of Single-Walled CNT Ropes

**The nanotube block has high mechanical strength and resistance to indentation.**

*Lyndon B. Johnson Space Center, Houston, Texas*

A 3D networked, dense form of single-walled carbon nanotubes (SWNT) has been made through isotropic shrinking of a gel-like SWNT-water paste by very slow evaporation. Approximately 35 g of Raw HiPco nanotubes were cleaned by the method of soft baking (250 °C for 15 hours in air saturated with water vapor) in a glass beaker followed by leaching with concentrated hydrochloric acid. Typically, one liter of concentrated hydrochloric acid was added to the soft-baked voluminous mass in the same large beaker, and allowed to digest at room temperature with stirring overnight. The acid-digested SWNT slurry was filtered through a large porcelain Buchner funnel under atmospheric pressure.

The slurry was continuously flushed, while still in the funnel, with a very slow but steady stream of deionized water employing a peristaltic pump. This process, referred to as “washing,” continued until the filtrate water dripping from the Buchner funnel was clear, colorless, and neutral to a pH paper. This took about 15 liters of water to flow through the slurry over a day. At this point, the water pump was stopped and the SWNT-water slurry was allowed to drain the excess water for about 10 hours. The resulting thick paste of SWNT-neutral water was transferred to a beaker. The beaker was covered with aluminum foil with few holes and allowed to dry very slowly in a hood at room temperature. In about eight weeks, the sam-

ple gradually dried isotropically to a cylindrical dense mass referred to as a carbon nanotube block (CNB).

There was no carbonaceous matter sticking to any of the glass surface where the SWNT-water paste made contact. The approximate dimensions of the cylindrical SWNT block that weighed 28 g were 1.5 in. ( $\approx 3.8$  cm) in diameter and 1.25 in. ( $\approx 3.2$  cm) in height. The bottom portion of the cylinder that was in contact with the beaker surface was slightly wider, indicating some resistance to shrinking. The cylindrical mass also consisted of several pores. The cylindrical mass was very tough and could not be broken with a small hammer using considerable force. The mass of the solid could be polished over a fine grain emery paper or even a smooth, stainless steel surface indicative of alignment at finer levels.

When attempting to cut with a sharp knife edge, the mass showed extreme resistance to the back-and-forth movement of the blade and indentation. Small portions were cut out of the solid block using a hacksaw and experimented. A small piece of the block was placed in water. It floated initially for a few minutes, but sank subsequently, indicative of a density  $>1$  g/cm<sup>3</sup>.

Two small portions (total volume approximately 1 cm<sup>3</sup>) were placed in a small, conical flask, and 25 ml of 100-percent H<sub>2</sub>SO<sub>4</sub> was added to that and closed with a ground-glass stopper. The

small pieces floated in 100-percent H<sub>2</sub>SO<sub>4</sub>. The SWNT block gradually swelled in volume and occupied the whole of the liquid volume ( $\approx 25$ cm<sup>3</sup>) in two days. The SWNT/100-percent H<sub>2</sub>SO<sub>4</sub> paste was very rigid and did not show fluidity. Scanning electron microscopy of the block showed evidence for the block to be constituted by packing of densely placed SWNT ropes. The polished surface showed evidence of a very high degree of smoothness up to 200 nm. The novelty and significance of this solid is the clear presence of a three dimensionally connected dense network of SWNT (with high mechanical strength) in a bulk form.

One immediate problem this new form of SWNT solves is handling. The dense form of SWNT is much easier to handle than the pristine forms of SWNT that could easily form potentially hazardous aerogels. The other bulk form of SWNT, known as buckypaper, needs ample time, equipment, and manpower to process; lacks mechanical strength; mostly retains the surfactants used in the process as organic impurities; and poses problems in redispersion to single-tube levels. The CNB, on the other hand, is made in a single step from the water-SWNT gel-like paste without recourse to any surfactant, possesses extreme mechanical strength, and can be redissolved in strong acids.

*This work was done by Richard E. Smalley of Rice University for Johnson Space Center. For*

*further information, contact the JSC Innovation Partnerships Office at (281) 483-3809.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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Refer to MSC-24059-1, volume and number of this NASA Tech Briefs issue, and the page number.*





## ⚙️ Axel Robotic Platform for Crater and Extreme Terrain Exploration

Other applications include exploration, search and rescue, and open-pit mining.

NASA's Jet Propulsion Laboratory, Pasadena, California

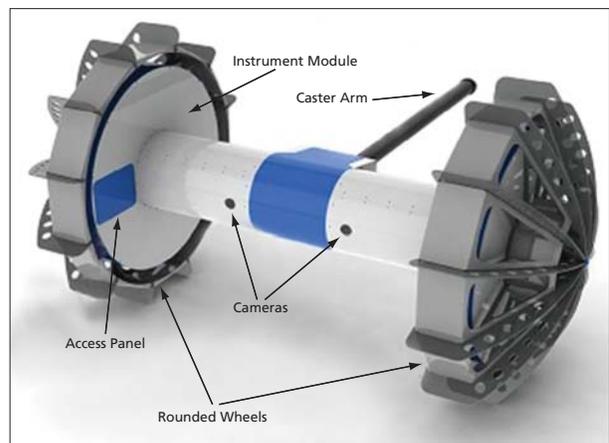
To be able to conduct science investigations on highly sloped and challenging terrains, it is necessary to deploy science payloads to such locations and collect and process *in situ* samples. A tethered robotic platform has been developed that is capable of exploring very challenging terrain. The Axel rover is a symmetrical rover that is minimally actuated, can traverse arbitrary paths, and operate upside-down or right-side up. It can be deployed from a larger platform (rover, lander, or aerobot) or from a dual Axel configuration. Axel carries and manages its own tether, reducing damage to the tether during operations.

Fundamentally, Axel is a two-wheeled rover with a symmetric body and a trailing link. Because the primary goal is minimal complexity, this version of the Axel rover uses only four primary actuators to control its wheels, tether, and a trailing link. A fifth actuator is used for level winding of tether onto Axel's spool.

The link serves multiple purposes: it provides a reaction lever arm against wheel thrust, it adjusts the rover's pitch for pointing its sensors and sampling devices, and it provides redundancy if one of the wheel actuators fails. Turning the trailing link into the ground in lieu of driving the wheels causes the rover body to roll and leads to forward motion of the rover. This tumbling mode of operation has several advantages for operating on slopes and for rolling off rocks if the rover high-centers its body on a rock. Using its tether, Axel is capable of driving down and up steep crater walls and lowering itself down from overhangs or into caves. Running the tether through the trailing link gives Axel greater stability and provides a restoring force for the link, keeping it off the ground during steep slope operations.

Because of its simple design, Axel can readily support different wheel types and sizes ranging from large, foldable wheels to inflatable ones. In this way, it can traverse steep and rocky terrains and tolerate strong impacts during landing or driving. In the case of umbrella foldable wheels, it can change its wheel size depending on the terrain roughness and corresponding rock sizes. Axel wheels have been designed with paddles to enable the rover to traverse rocks that are a wheel radius tall.

This generation of Axel has two science bays, which are large cylinders that fit into and are covered by Axel's cantilevered wheels. These bays can accommodate up to four small science instruments each. The contact instruments are deployed to the ground via a single-degree-of-freedom, four-bar mechanism. Some optical instruments do not require any deployment and can operate after pointing these sensors using the body actuators. Sampling devices such as a scoop or coring drill may also be deployed by the four-bar mechanism.



The third-generation **Axel Two-Wheeled Rover** features a symmetric body and a trailing link, and uses only four primary actuators to control its wheels, tether, and trailing link.

Axel co-locates its sensors, actuators, electronics, power, and payload inside the central cylinder and science bays. This configuration provides compactness for launch, and robustness against environmental extremes in planetary missions. The Axel rover is equipped with science instruments, computational and communication modules, stereo cameras, and an inertial sensor for autonomous navigation with obstacle avoidance. Conductors inside the tether allow for the deployed Axel to be charged from and

communicate with the parts of the system that remain topside.

A mission can use a single or multiple low-mass Axel rovers to explore and sample high-risk sites. This class of rovers provides new capabilities for steep terrain and cave exploration and sampling beyond what is offered by current state-of-the-art rovers.

*This work was done by Issa A. Nesnas, Jaret B. Matthews, Jeffrey A. Edlund, Joel W. Burdick, and Pablo Abad-Manterola of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

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*Refer to NPO-47890, volume and number of this NASA Tech Briefs issue, and the page number.*

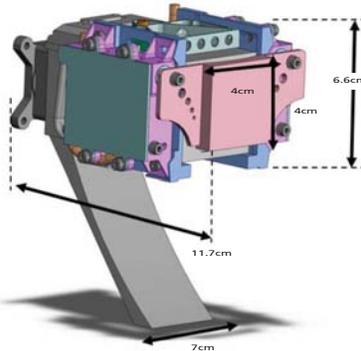
## ⚙️ Site Tamper and Material Plow Tool — STAMP

**Tool simplifies measurement of surface samples.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A non-actuated tool has been developed for preparing regolith for in situ measurement by smoothing uneven surfaces and excavating fresher subsurface material for planetary exploration. The STAMP tool contains two tools to prepare regolith for in situ measurement: a tamper to smooth uneven surfaces, and a blade to excavate fresher subsurface material.

The STAMP design leverages flight-proven design features and flight-qualified components from Mars Exploration Rover (MER) and Phoenix missions to provide a reli-



The STAMP Tool contains a tamper to smooth uneven surfaces, and a blade to excavate fresher subsurface material.

able, non-actuated tool. The STAMP tool can be mounted at the end-effector of a robotic arm that supports deployment of contact instruments. Using the rotation of the end-effector, either the tamper or blade can be deployed to prepare regolith for *in situ* measurement.

*This work was done by Norman M. Aisen, Curtis L. Collins, and Ashitey Trebi-Ollennu of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47742*

## ⚙️ Magnetic Interface for Segmented Mirror Assembly

*Marshall Space Flight Center, Alabama*

Newly developed magnetic devices are used to create an interface between adjacent mirror segments so that once assembled, aligned, and phased, the multiple segments will behave functionally equivalent to a monolithic aperture mirror. One embodiment might be a kinematic interface that is reversible so that any number of segments can be pre-assembled, aligned, and phased to facilitate fabrication operations, and then disassembled and reassembled, aligned, and phased in space for operation.

The interface mechanism has sufficient stiffness, force, and stability to maintain phasing. The key to producing an interface is the correlated mag-

netic surface. While conventional magnets are only constrained in one direction — the direction defined by their point of contact (they are in contact and cannot get any closer) — correlated magnets can be designed to have constraints in multiple degrees of freedom. Additionally, correlated magnetic surfaces can be designed to have a limited range of action.

Finally, via the use of electromagnets, the rate of closure or separation of correlated magnetic surfaces can be controlled. Once the interface is established, mechanisms will adjust the segment alignment relative to each other to establish phasing. Once phas-

ing is established, the correlated magnetic surfaces have sufficient axial and lateral force to maintain that alignment in the microgravity environment of space. Additionally, beyond providing a hard interface, the axial and lateral force (spring constants) of the correlated magnetic surfaces can be designed to provide a very stiff or very soft interface. The net effect is similar to a kinematic mechanical flexure system, a tuned dampener, or shock absorber.

*This work was done by H. Stahl of Marshall Space Flight Center. For more information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32917-1.*

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## Transpiration-Cooled Spacecraft-Insulation-Repair Fasteners

*Lyndon B. Johnson Space Center, Houston, Texas*

Transpiration-cooled fasteners are proposed that operate like an open-loop heat pipe (self-tapping screws, bolts, and spikes) for use in on-orbit repair of thermal-insulation of a space shuttle or other spacecraft. By limiting the temperature rise of such a fastener and of the adjacent repair material and thermal protection system, the transpiration cooling would contribute to the ability of the repair to retain its strength and integrity in the high-heat-flux, oxidizing environment of re-entry into the atmosphere of the Earth.

A typical fastener according to the proposal would include a hollow refractory-metal, refractory-composite, or ceramic screw or bolt, the central cavity of which would be occupied by a porous refractory-metal or ceramic plug that would act as both a reservoir and a wick for a transpirant liquid. The plug dimensions, the plug material, and the sizes of the pores would be chosen in conjunction with the transpirant liquid so that (1) capillary pumping could be relied upon to transport the liquid to the heated surface,

where the liquid would be vaporized, and (2) the amount of liquid would suffice for protecting against the anticipated heat flux and integrated heat load.

*This work was done by Charles J. Camarda and Donald R. Pettit of Johnson Space Center; David Glass, Stephen J. Scotti, and Wallace Lee Vaughn of Langley Research Center; and Suraj Rawal of Lockheed Martin Corp. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809. MSC-23908-1*





## Fluorescence-Based Sensor for Monitoring Activation of Lunar Dust

This sensor also is suitable for assessing safety and health in the cement and fly ash industries.

*Lyndon B. Johnson Space Center, Houston, Texas*

This sensor unit is designed to determine the level of activation of lunar dust or simulant particles using a fluorescent technique. Activation of the surface of a lunar soil sample (for instance, through grinding) should produce a freshly fractured surface. When these reactive surfaces interact with oxygen and water, they produce hydroxyl radicals. These radicals will react with a terephthalate diluted in the aqueous medium to form 2-hydroxyterephthalate. The fluorescence produced by 2-hydroxyterephthalate provides qualitative proof of the activation of the sample. Using a calibration curve produced by synthesized 2-hydroxyterephthalate, the amount of hydroxyl radicals produced as a function of sample concentration can also be determined.

There are five main components to the sensor unit: cuvette holder, quartz cuvette, power/control electronics board, software, and a data acquisition board. The quartz cuvette holder will be made of an optically opaque material in order to decrease the possibility of scattered light. An ultraviolet LED producing light in the range of 310–330 nm, and a Si photodiode detector, will be mounted to the walls of the flow cell holder directly opposite one another to form the optical axis.

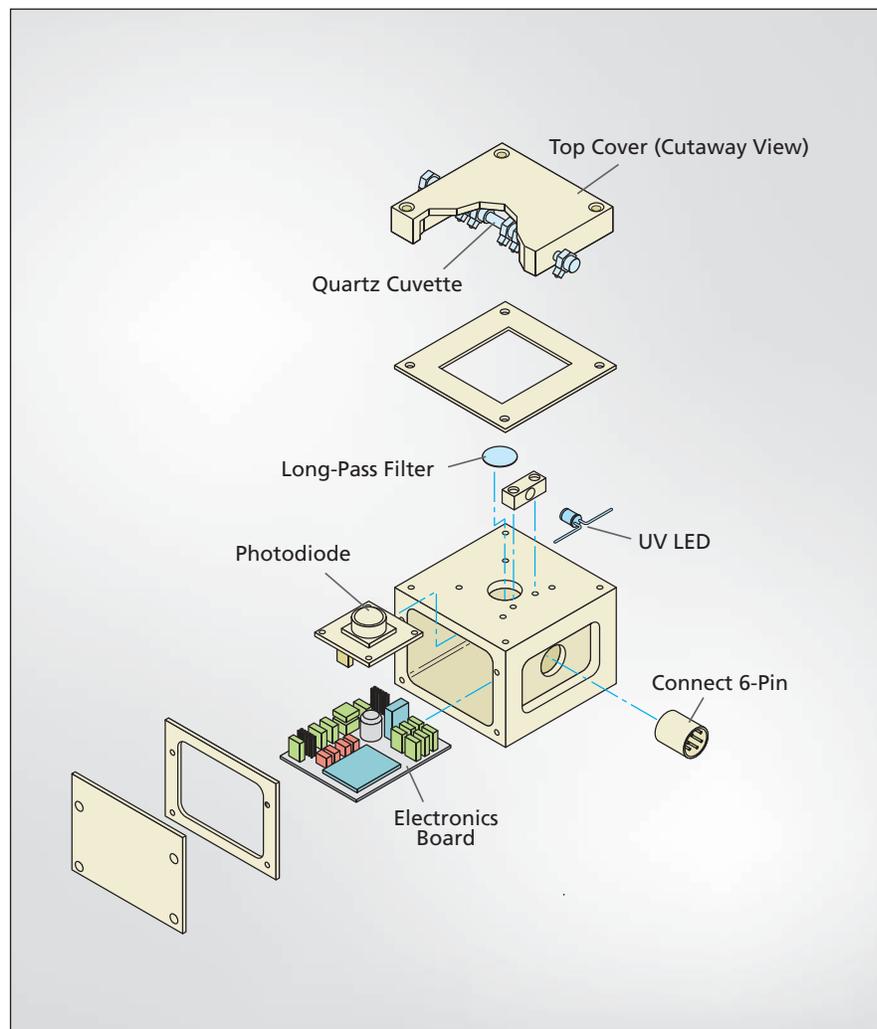
There are two possible configurations for the sample cuvette. First, test solution could be introduced into a standard, capped quartz cuvette. After testing, the cuvette could be removed and cleaned prior to further testing. Alternatively, a flow-through quartz cuvette could be used. After monitoring the fluorescence intensity of the test solution, the solution can be removed by pumping or other methods.

The power/control electronics board will provide power to the LED and the photodiode, control the LED, and amplify the analog output of the photodiode. Power will be provided by a DC–DC converter, filtered through an LC circuit, and fed to linear voltage regulators to generate clean, stable, positive and negative voltages.

The software is a virtual instrument written in LabVIEW v.6i. From the virtual instrument, the time of illumination can be controlled, as well as data acquisition parameters such as scan rate. In addition, the virtual instrument will apply a user-set calibration curve to the data to obtain the hydroxyl radical concentration. All of the data collected, as well as the calculated hydroxyl radical concentration, will be plotted on the virtual instrument and stored automatically in a text file with a time and date stamp.

A National Instruments data acquisition board will be installed in a personal computer running Microsoft Windows XP. The analog output from the sensor will be fed to the data acquisition board, where it will be digitized. The data will be collected using the virtual instrument running LabVIEW.

For terrestrial activation studies, a small amount of sample will be placed into a mortar and ground using a pestle for 10 minutes. At approximately 2-minute intervals, the sides of the mortar



A possible design for the proposed Lunar Dust Activation Sensor.

should be scraped in order to ensure that all material is experiencing consistent grinding. At the completion of grinding, or during testing in the lunar environment, a portion of the activated material will be added to a solution consisting of disodium terephthalate diluted in phosphate-buffered saline (PBS) at a concentration of 10 mM. The concentra-

tion of the sample in solution should be at least 1 mg/mL in order to provide sufficient fluorescence intensity. After allowing the sample to interact with the solution for 30 minutes, the mixture will be filtered using a 0.2-micron filter. The filtered solution will be placed in the quartz cuvette, and emission spectra will be obtained using an excitation wave-

length of approximately 324 nm. The emission spectra will be compared to the calibration curve made using pure 2-hydroxyterephthalate.

*This work was done by William T. Wallace of Universities Space Research Association and Antony S. Jeevarajan of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24446-1*

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## Aperture Ion Source

**The aperture ion source has application in commercial mass spectrometers.**

*Goddard Space Flight Center, Greenbelt, Maryland*

The aperture ion source was conceived to eliminate distortion in measurements of angular distributions of neutral atoms and molecules that require electron-impact ion sources. The approach simplifies the coupling between ion source and spectrometer while providing virtually distortion-free angular distributions and improved accuracy in the dimensions of the ionization region. Furthermore, it virtually eliminates the volume occupied by the ion source.

The basic idea is to place the ionization region in the aperture to the energy-angle analyzer or mass spectrometer. Electron impact ionization of neutrals prior to analysis is used here as in conventional ion sources. Implementation of the idea embeds the ionizing electrons in a very narrow space immediately above the spectrometer entrance aperture, leading to improved performance over the present extended ion source configuration. In order to ensure a field-free ionization volume, the ionization space is defined by two plates with identical apertures, the central plane between the two serving as the object plane for the spectrometer. Therefore, the effective position of the en-

trance aperture to the spectrometer lies in the middle of the ionization region. One of the goals is to provide an easy way to specify the position and dimensions of the ionization region. Thus, the smaller the ionization region, the easier the specification of the ionization region, and if done properly, the smaller the fraction of unused electrons in the electron beam. Making the ionization region as small as possible should also enhance ionization efficiency. This is actually borne out by a calculation comparing the ionization efficiencies of the present scheme to that of the aperture ion source.

The aperture ion source would operate as follows. One of the four cathodes is activated to emit ionizing electrons toward the ionization region. A collector just ahead of the diametrically opposite unused cathode registers the ionizing electron current. A fraction of the neutral atoms and molecules passing through the apertures is ionized and proceeds on to the interior of an energy-analyzer to give the energy-angle distribution of the original neutrals.

In addition to simplifying and enabling distortion-free measurement of

angular distributions of neutral atoms and molecules, this innovation offers a drastic reduction in ion source volume with improvements in ionization efficiency. This innovation also lends itself to mounting two, four, and possibly eight cathodes around the aperture to provide two, four, and eight-fold redundancy to improve reliability.

The formulation process of this idea showed that the aperture ion source offers higher efficiency over conventional ion sources that ionize the neutral gas at some distance from the entrance aperture of the spectrometer. In addition, it offers well-defined ionization volume for careful quantitative analysis using mass spectrometers. Most commercial mass spectrometers use such electron impact ionization ion sources with issues of operation downtime due to cathode replacement. The cathode redundancy that comes with this innovation would reduce downtime by at least a factor of four.

*This work was done by Fred Herrero of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-16145-1*



## Virtual Ultrasound Guidance for Inexperienced Operators

**This audio/video system provides real-time help to inexperienced ultrasound operators in remote environments.**

*Lyndon B. Johnson Space Center, Houston, Texas*

Medical ultrasound or echocardiographic studies are highly operator-dependent and generally require lengthy training and internship to perfect. To obtain quality echocardiographic images in remote environments, such as on-orbit, remote guidance of studies has been employed. This technique involves minimal training for the user, coupled with remote guidance from an expert. When real-time communication or expert guidance is not available, a more autonomous system of guiding an inexperienced operator through an ultrasound study is needed. One example would be missions beyond low Earth orbit, in which the time delay inherent with communication will make remote guidance impractical.

The Virtual Ultrasound Guidance system is a combination of hardware and software. The hardware portion includes, but is not limited to, video glasses that allow hands-free, full-screen

viewing. The glasses also allow the operator a substantial field of view below the glasses to view and operate the ultrasound system. The software is a comprehensive video program designed to guide an inexperienced operator through a detailed ultrasound or echocardiographic study without extensive training or guidance from the ground. The program contains a detailed description using video and audio to demonstrate equipment controls, ergonomics of scanning, study protocol, and scanning guidance, including recovery from sub-optimal images.

The components used in the initial validation of the system include an Apple iPod Classic third-generation as the video source, and Myvue video glasses. Initially, the program prompts the operator to power-up the ultrasound and position the patient. The operator would put on the video glasses and attach them to the video source.

After turning on both devices and the ultrasound system, the audio-video guidance would then instruct on patient positioning and scanning techniques.

A detailed scanning protocol follows with descriptions and reference video of each view along with advice on technique. The program also instructs the operator regarding the types of images to store and how to overcome pitfalls in scanning. Images can be forwarded to the ground or other site when convenient. Following study completion, the video glasses, video source, and ultrasound system are powered down and stored. Virtually any equipment that can play back video can be used to play back the program. This includes a DVD player, personal computer, and some MP3 players.

*This work was done by Timothy Caine and David Martin of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-24800-1*





## Model-Based Fault Diagnosis: Performing Root Cause and Impact Analyses in Real Time

The methodology and its required interfaces have been implemented to become a commercial product for integrated systems health management.

*Stennis Space Center, Mississippi*

Generic, object-oriented fault models, built according to causal-directed graph theory, have been integrated into an overall software architecture dedicated to monitoring and predicting the health of mission-critical systems. Processing over the generic fault models is triggered by event detection logic that is defined according to the specific functional requirements of the system and its components. Once triggered, the fault models provide an automated way for performing both upstream root cause analysis (RCA), and for predicting downstream effects or impact analysis. The methodology has been applied to integrated system health management (ISHM) implementations at NASA SSC's Rocket Engine Test Stands (RETS).

Previous SSC ISHM systems have focused on integrating distributed smart sensor data into a centralized object model, and on providing high-level, rule-based reasoning for RETS health monitoring. The SSC ISHM did not include advanced health monitoring techniques such as correlation of events at the system level, automated fault diagnosis, failure prediction, root cause analysis, or predictive analysis. The key functional enhancement targeted for ISHM by this project has been the de-

velopment of an automated, generic, fault-tree-based RCA module designed to enable these additional capabilities. By choosing a generic, model-based diagnostic methodology, a more complete assessment/evaluation of system health is empowered, while advanced techniques for isolating root causes and predicting the onset of failure are enabled. The objective was to create a library of reusable fault models and correlation logic for use across multiple programs.

The domain-specific insight necessary to perform the design and implementation tasks at SSC has been acquired through scheduled discussions with RETS test engineers and scientists. Where possible, validation of these enhancements took place using real-time operational data, as well as of historical data. A discrete number of generic failure modes can typically be identified for many of the components within an ISHM system model. Failure modes are distinct mechanisms by which the components can fail. From these failure modes, it is possible to construct a fault model — a directed graph that depicts the causal relationships between the component failure modes and any of the observable (or measure-

able) downstream effects. The nodes in the fault model represent these measurable effects, and the directed connections between the nodes characterize both their causal relationships as well as any appropriate constraints that might apply. Within an ISHM system, such generic fault models can be traversed by software to determine the causes of abnormal system behavior. The models can also be traversed for predicting the downstream impacts. While traversing all applicable fault models upon receipt of detected events, ISHM software can also perform the necessary tests to diagnose and isolate the root causes of problems, ruling out other possible explanations that are not substantiated by event data.

*This work was done by Jorge F. Figueroa of Stennis Space Center; Mark G. Walker and Ravi Kapadia of General Atomics; and Jonathan Morris of Jacobs Technology. Inquiries concerning rights for the commercial use of this invention should be addressed to:*

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## Interactive Schematic Integration Within the Propellant System Modeling Environment

Commercial areas of interest include automotive engine components, petroleum refineries and offshore rigs, and industrial machinery builders.

*Stennis Space Center, Mississippi*

Task requirements for rocket propulsion test preparations of the test stand facilities drive the need to model the test facility propellant systems prior to constructing physical modifications. The Propellant System Modeling Environment (PSME) is an initiative designed to enable increased efficiency and expanded capa-

bilities to a broader base of NASA engineers in the use of modeling and simulation (M&S) technologies for rocket propulsion test and launch mission requirements. PSME will enable a wider scope of users to utilize M&S of propulsion test and launch facilities for predictive and post-analysis functionality by offering

a clean, easy-to-use, high-performance application environment.

PSME Interactive Schematic (IS) is an innovative function that augments PSME's client application to become more efficient by increasing intuitive operation in the model configuration phase. IS diagrams of propellant system

components are tied to primary parameter values of a given model configuration. Changes to parameter values are integrated with components of the diagram, dynamically depicting corresponding changes within the diagram. This serves as a visual confirmation of the configuration change made.

The Pressurant Tank IS enables the representation of editable liquid propellant Rocket Propulsion Test Analysis (RPTA) core model configuration parameters as textbox controls, annotating a graphical Pressurant Tank

schematic. Edits made within the text boxes reflect dynamically in a changed visual state of the schematic. This enables a first-ever means for editing RPTA model configuration parameters in a visual context of the configuration component being affected.

The prototype development of schematic interaction utilizes Excel's pre-defined graphics called auto-shapes, requiring no other coding or external licensing of other software. The new interactive schematic function, designed as a top layer skin, enables rapid devel-

opment and customization with little change to the underlying Model Configuration Editor (MCE). PSME's client application interactive schematics design allows for quick and efficient customizations that may be required in support of mission activities.

*This work was done by David Coote and Harry Ryan of Stennis Space Center, and Kenneth Burton, Lee McKinney, Don Woodman of Computer Sciences Corporation. For more information, call the Innovative Partnerships Office at 228-688-1929. SSC-00351*

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## ➤ Magnetic and Electric Field Polarizations of Oblique Magnetospheric Chorus Waves

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A theory was developed to explain the properties of the chorus magnetic and electric field components in the case of an arbitrary propagation angle. The new theory shows that a whistler wave has circularly polarized magnetic fields for oblique propagation. This theoretical result is verified by GEOTAIL observations. The wave electric field polarization plane is not orthogonal to the wave vector, and in general is highly elliptically polarized. A special case of the whistler wave called the

Gendrin mode is also discussed. This will help to construct a detailed and realistic picture of wave interaction with magnetosphere electrons.

It is the purpose of this innovation to study the magnetic and electric polarization properties of chorus at all frequencies, and at all angles of propagation. Even though general expressions for electromagnetic wave polarization in anisotropic plasma are derived in many textbooks, to the knowledge of the inno-

vators, a detailed analysis for oblique whistler wave mode is lacking. Knowledge of the polarization properties is critical for theoretical calculations of resonant wave-particle interactions.

*This work was done by Olga Verkhoglyadova and Bruce T. Tsurutani of Caltech, and Gurbax S. Lakhina of the Indian Institute of Geomagnetism for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47770*

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## ➤ Variable Sampling Mapping

*Goddard Space Flight Center, Greenbelt, Maryland*

The performance of an optical system (for example, a telescope) is limited by the misalignments and manufacturing imperfections of the optical elements in the system. The impact of these misalignments and imperfections can be quantified by the phase variations imparted on light traveling through the system. Phase retrieval is a methodology for determining these variations. Phase retrieval uses images taken with the optical system and using a light source of known shape and characteristics. Unlike interferometric methods, which require an optical reference for comparison, and unlike Shack-Hartmann wavefront sensors that require special optical hardware at the optical system's exit pupil, phase retrieval is an *in situ*, "image-based" method for determining the phase variations of light at the system's exit pupil. Phase retrieval can be

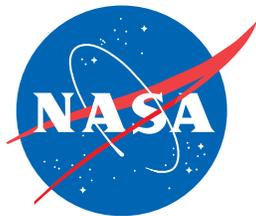
used both as an optical metrology tool (during fabrication of optical surfaces and assembly of optical systems) and as a sensor used in active, closed-loop control of an optical system, to optimize performance. One class of phase-retrieval algorithms is the iterative transform algorithm (ITA). ITAs estimate the phase variations by iteratively enforcing known constraints in the exit pupil and at the detector, determined from modeled or measured data.

The Variable Sampling Mapping (VSM) technique is a new method for enforcing these constraints in ITAs. VSM is an open framework for addressing a wide range of issues that have previously been considered detrimental to high-accuracy phase retrieval, including undersampled images, broadband illumination, images taken at or near best focus, chromatic aberrations, jitter or vibration of the opti-

cal system or detector, and dead or noisy detector pixels. The VSM is a model-to-data mapping procedure. In VSM, fully-sampled electric fields at multiple wavelengths are modeled inside the phase-retrieval algorithm, and then these fields are mapped to intensities on the light detector, using the properties of the detector and optical system, for comparison with measured data. Ultimately, this model-to-data mapping procedure enables a more robust and accurate way of incorporating the exit-pupil and image detector constraints, which are fundamental to the general class of ITA phase retrieval algorithms.

*This work was done by Jeffrey S. Smith, David L. Aronstein, Bruce H. Dean, and Richard G. Lyon of Goddard Space Flight Center. Further information is contained in a TSP (see page 1). GSC-15693-1*





National Aeronautics and  
Space Administration