











TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

-  **Technology Focus**
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-  **Software**
-  **Materials**
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-  **Machinery/Automation**
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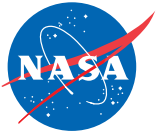
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TECH BRIEFS

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Technology Focus: Fastening/Joining/Assembly Technologies

Stable, Thermally Conductive Fillers for Bolted Joints

Lyndon B. Johnson Space Center, Houston, Texas

A commercial structural epoxy [Super Koropon (or equivalent)] has been found to be a suitable filler material for bolted joints that are required to have large thermal conductances. The contact area of such a joint can be less than 1 percent of the apparent joint area, the exact value depending on the roughnesses of the mating surfaces. By occupying the valleys between contact peaks, the filler widens the effective cross section for thermal conduction. In comparison with prior thermal joint-filler materials, the present epoxy offers advantages of stability, ease of application, and — as a byproduct of its stability

— lasting protection against corrosion. Moreover, unlike silicone greases that have been used previously, this epoxy does not migrate to contaminate adjacent surfaces. Because this epoxy in its uncured state wets metal joint surfaces and has low viscosity, it readily flows to fill the gaps between the mating surfaces: these characteristics affect the overall thermal conductance of the joint more than does the bulk thermal conductivity of the epoxy, which is not exceptional. The thermal conductances of metal-to-metal joints containing this epoxy were found to range between 5 and 8 times those of unfilled joints.

This work was done by Raymond J. LeVesque II; Cherie A. Jones; and Henry W. Babel of McDonnell Douglas Corp. for Johnson Space Center. Further information is contained in a TSP (see page 1).

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act [42 USC 2457 (f)], to The Boeing Co.

P.O. Box 2515/MS8WSB43
Seal Beach, CA 90740-1515

Refer to MSC-23066, volume and number of this NASA Tech Briefs issue, and the page number.

Connecting to Thermocouples With Fewer Lead Wires

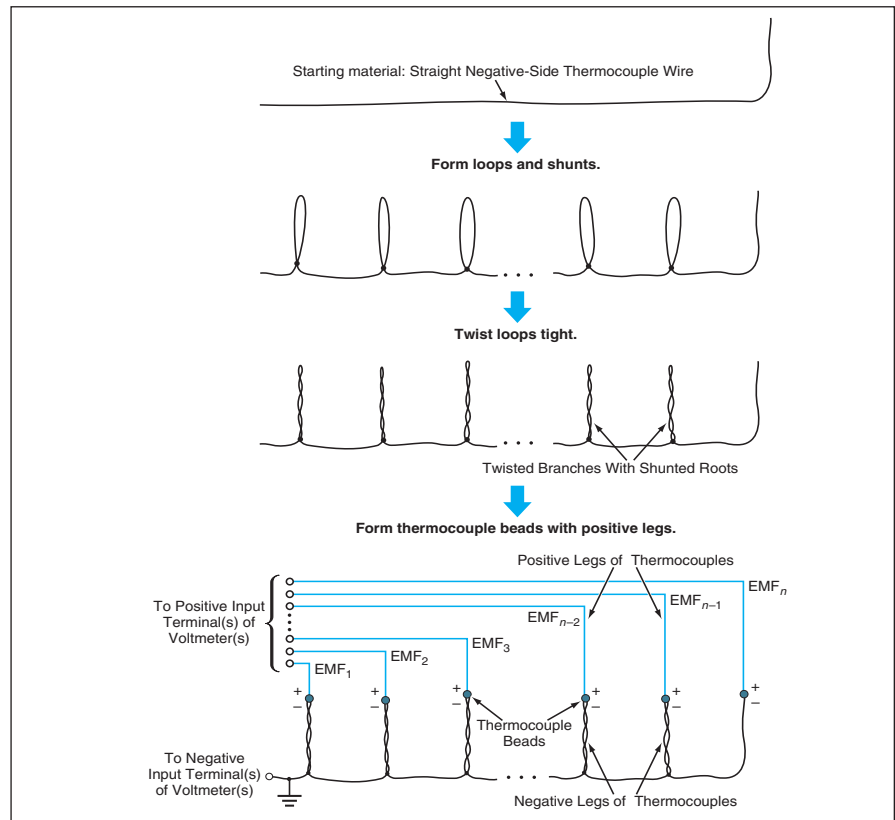
For N thermocouples, only $N + 1$ wires are needed.

John H. Glenn Research Center, Cleveland, Ohio

A simple technique has been devised to reduce the number of lead wires needed to connect an array of thermocouples to the instruments (e.g., voltmeters) used to read their output voltages. Because thermocouple wires are usually made of expensive metal alloys, reducing the number of lead wires can effect a considerable reduction in the cost of such an array. Reducing the number of wires also reduces the number of terminals and the amount of space needed to accommodate the wires.

Heretofore, it has been standard practice to use a separate lead wire to connect to each side of each thermocouple. In other words, it has been standard practice to use $2N$ lead wires to connect to N thermocouples.

The essence of the present technique is to use one common, grounded wire for the negative sides of all the thermocouples in the array and to connect the positive side of each thermocouple, in the customary manner, to the positive terminal of the instrument used to read its output. Fabrication of the array begins with twisting of the single negative-side wire to form branches for thermocouples (see figure). The



A Single Common Wire for the negative sides of N thermocouples is formed into a branched wire. The thermocouples are formed at the tips of the branches.

root of each twisted branch is then heated to shunt the twist, thereby reforming the twisted and untwisted portions of the wire into a continuous piece of branched wire. Next, thermocouples are formed by joining one end of each positive lead wire to the tip of one of the twisted branches and the

other end to one of the output terminals. If the number of thermocouples formed in this way is N , then there are only $N + 1$ lead wires (the one common negative wire and N positive wires) and an equal number of terminals.

This work was done by Jon C. Goldsby of Glenn Research Center. Further

information is contained in a TSP (see page 1).

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17181.

Zipper Connectors for Flexible Electronic Circuits

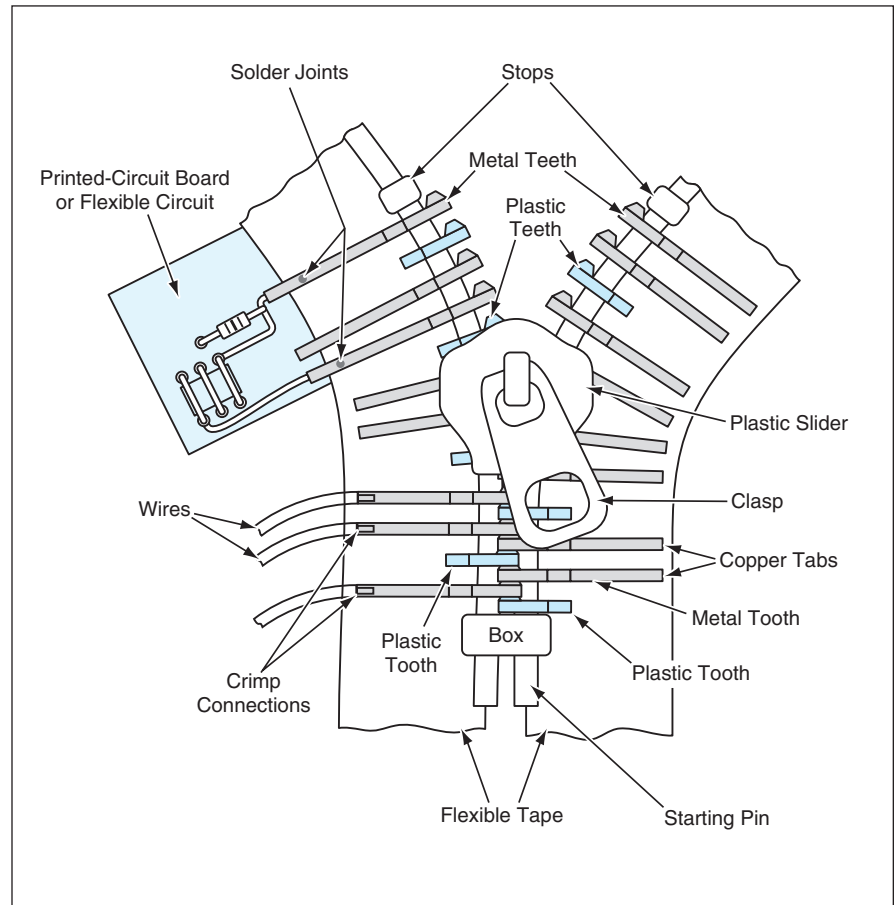
Circuits could be connected and disconnected quickly and easily.

Langley Research Center, Hampton, Virginia

Devices that look and function much like conventional zippers on clothing have been proposed as connectors for flexible electronic circuits. Heretofore, flexible electronic circuits have commonly included rigid connectors like those of conventional rigid electronic circuits. The proposed zipper connectors would make it possible to connect and disconnect flexible circuits quickly and easily. Moreover, the flexibility of zipper connectors would make them more (relative to rigid connectors) compatible with flexible circuits, so that the advantages of flexible circuitry could be realized more fully.

Like a conventional zipper, a zipper according to the proposal would include teeth anchored on flexible tapes, a slider with a loosely attached clasp, a box at one end of the rows of mating teeth, and stops at the opposite ends (see figure). The tapes would be made of a plastic or other dielectric material. On each of the two mating sides of the zipper, metal teeth would alternate with dielectric (plastic) teeth, there being two metal teeth for each plastic one. When the zipper was closed, each metal tooth from one side would be in mechanical and electrical contact with a designated metal tooth from the other side, and these mating metal teeth would be electrically insulated from the next pair of mating metal teeth by an intervening plastic tooth. The metal teeth would be soldered or crimped to copper tabs. Wires or other conductors connected to electronic circuits would be soldered or crimped to the ends of the tabs opposite the teeth.

The pitch (that is, the distance along the zipper between mating pairs of metal teeth) would be a major consideration in design. It has been esti-



A Zipper Connector for electronic circuitry would resemble a conventional clothing zipper in several respects.

mated that a pitch of 100 mils (≈ 2.5 mm) can be achieved by known fabrication techniques and that pitches as small as 25 mils (≈ 0.6 mm) may eventually be achievable. Problems that remain to be solved include how to prevent short-circuiting of exposed teeth in contact with external electrically conductive objects and how to prevent corrosion of the teeth. The short-circuiting problem could be solved by adding a dielectric flap that would

cover the teeth. The corrosion problem might be solved by use of gold contacts; the other option would be to add a water-tight seal, but such a seal could reduce or eliminate the advantage of quick and easy connection and disconnection.

This work was done by Kevin N. Barnes of Langley Research Center. Further information is contained in a TSP (see page 1). LAR-16320

Safety Interlock for Angularly Misdirected Power Tool

Power would be turned off when the tool was aimed in the wrong direction.

Lyndon B. Johnson Space Center, Houston, Texas

A proposed safety system would effect an inhibitory action whenever a power tool was aimed in a direction outside a prescribed range of allowable directions. The power tool could be a welding torch, blowtorch, laser, drill, or gun, for example. The inhibitory action could be turning off the supply of gas or electric power to the tool; in the case of a gun, the inhibitory action could be actuation of a mechanical trigger stop.

The safety system would include at least two rate-of-rotation sensors (one for pitch and one for yaw), an electronic circuit that would generate an “inhibit” command, and a mechanism that would effect the inhibitory action upon receipt of the “inhibit” command. The two rate-of-rotation sensors could be based on gyroscopes and could be combined in a single package; the preferred package would be a commercial dynamically tuned two-axis-gyroscope unit that has a rate range of 200° per second and a steady-state power consumption of ≈ 1 W. The rate-of-rotation sensors should be positioned so that their principal axes of pitch and yaw intersect at approxi-

mately the location designated as the center of the tool.

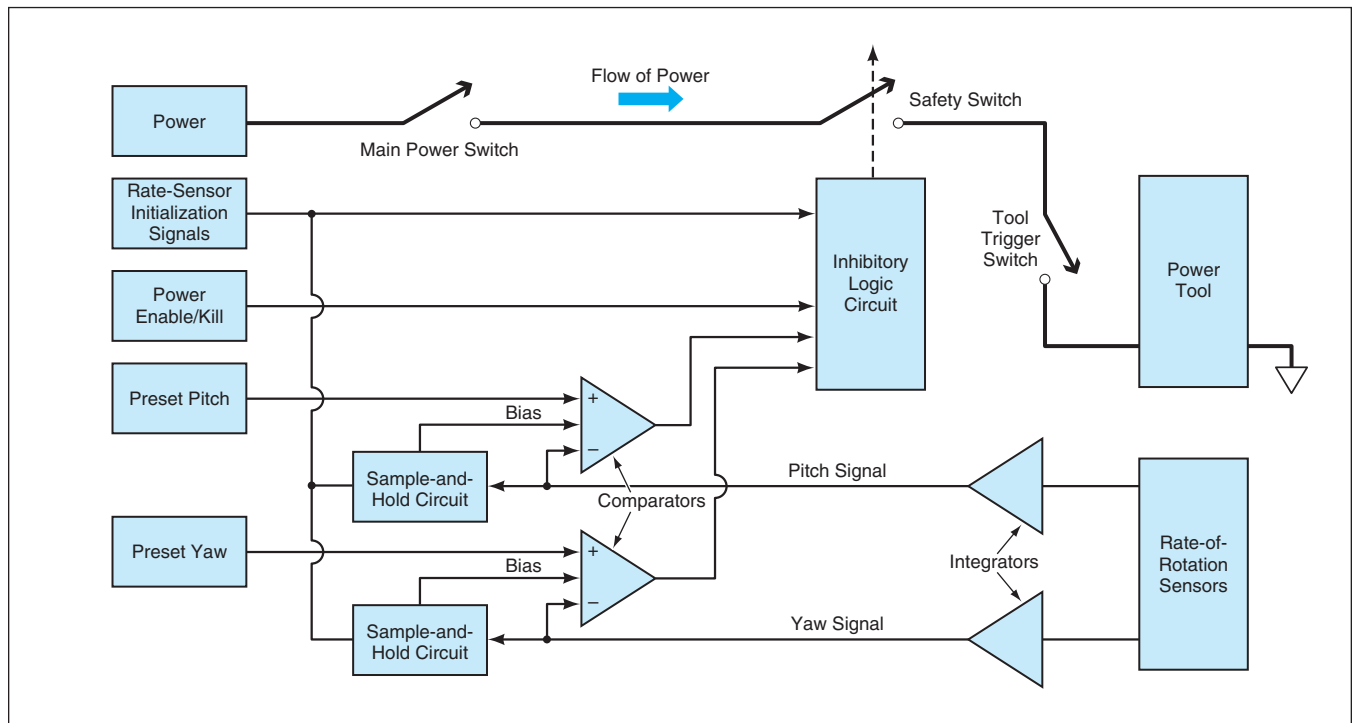
The figure schematically depicts the main power-control circuit and the safety system as they would be configured in a typical application to an electrically powered tool. Electric power would be supplied to the tool through three switches: a main (manually actuated switch), a safety switch under control by the circuitry described below, and a tool-trigger switch. The electronic circuitry in the safety system would include integrators that would convert the outputs of the yaw- and pitch-rate sensors to yaw- and pitch-angle signals, respectively.

The yaw- and pitch-angle signals would be fed to the inverting inputs of yaw- and pitch-angle-signal comparators, while preset yaw and pitch signals would be fed to the noninverting inputs of these comparators. Along with rate-sensor-initialization signals, the yaw- and pitch-angle signals would also be processed through sample-and-hold circuits, the outputs of which would be used to bias the comparators such that each comparator would put out a logical “1” when the corresponding yaw or

pitch angle deviated from a desired aiming direction by more than a preset amount of yaw or pitch, respectively.

The outputs of the comparators would be fed to an inhibitory logic circuit that would allow power to be supplied to the tool when (1) the rate-sensor-initialization signal was asserted, (2) the operator had pressed a “power enable/kill” push-button switch to signal the intention to operate the tool, and (3) the tool was aimed within the angular bounds described above. Under all other conditions, the inhibitory logic circuit would generate the “inhibit” command, which, in this case, would cause the safety switch to shut off power to the tool. If the tool were a gas-fed welding torch, then the inhibitory mechanism could include an electrically actuated valve instead of (or in addition to) a safety switch. If the tool were a gun, then the inhibitory mechanism could be an electromechanical trigger stop.

The sequence of operation of the tool and safety system would be the following: The pitch and yaw angular limits would have been preset by the operator. The operator would point the tool at



Power To Operate a Tool would be fed through three switches, one of which would be part of the safety system. The safety switch would shut off power to the tool, except when the tool was aimed within preset angular bounds and the operator had signaled the intention to operate the tool.

the work site and would assert the rate-sensor-initialization signal (this could be done by pressing a push-button switch). The initial orientation of the tool would then be “remembered” as the desired aiming direction (“homing” direction). Then the operator would press the “power enable/kill” button. Finally, the operator would begin to operate the tool by pulling its trigger. Whenever the tool was aimed outside the angular limits, safety system would shut off power to the tool.

Unlike safety systems based on mechanical restraints, the proposed system would not make the operator’s task more difficult or adversely affect the quality of the work. Unlike magnetic-

and optical-sensor-based safety systems, the proposed system would not require the setup and calibration of an external reference subsystem. Unlike an optical-sensor-based safety system, the proposed system would not be susceptible to interference by ambient light. In comparison with a magnetic-sensor-based system, the proposed system would be less susceptible to electromagnetic interference. The proposed system is also expected to cost less than the optical and magnetic systems do.

The proposed system would have some limitations:

- The rate-of-rotation sensors would be sensitive to the rotation of the Earth. The rate of buildup of angular error

due to rotation of the Earth should be no greater than about 0.25° per minute.

- Some drift errors may be generated in integration of the outputs of the rate-of-rotation sensors. Errors of this type are typically about 1° per minute.
- The system would inhibit operation in the event of translational mispositioning of the tool.
- The system would not prevent injury to a person who stepped in front of the tool, in a region that fell within the preset angular bounds.

This work was done by Larry C. Li of Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-22817



Modular, Parallel Pulse-Shaping Filter Architectures

Properties of filters and signals would be exploited to simplify processing circuits.

NASA's Jet Propulsion Laboratory, Pasadena, California

Novel architectures based on parallel subconvolution frequency-domain filtering methods have been developed for modular processing rate reduction of discrete-time pulse-shaping filters. Such pulse-shaping is desirable and often necessary to obtain bandwidth efficiency in very-high-rate wireless communications systems. In principle, this processing could be implemented in very-large-scale integrated (VLSI) circuits. Whereas other approaches to digital pulse-shaping are based primarily on time-domain processing concepts, the theory and design rules of the architectures presented here are founded on frequency-domain processing that has advantages in certain systems.

A major advantage of parallel processing of signal data, whether for shaping pulses or other purposes, is that the data rate in each of the parallel streams is much lower than the overall data rate. This makes it possible to use processing circuitry that is slower than what would be needed to process all of the data in a single stream. In particular, it becomes possible to use complementary metal oxide semiconductor (CMOS) circuitry instead of faster and more expensive GaAs-based circuitry. The present frequency-domain approach to parallel processing offers the following additional advantages:

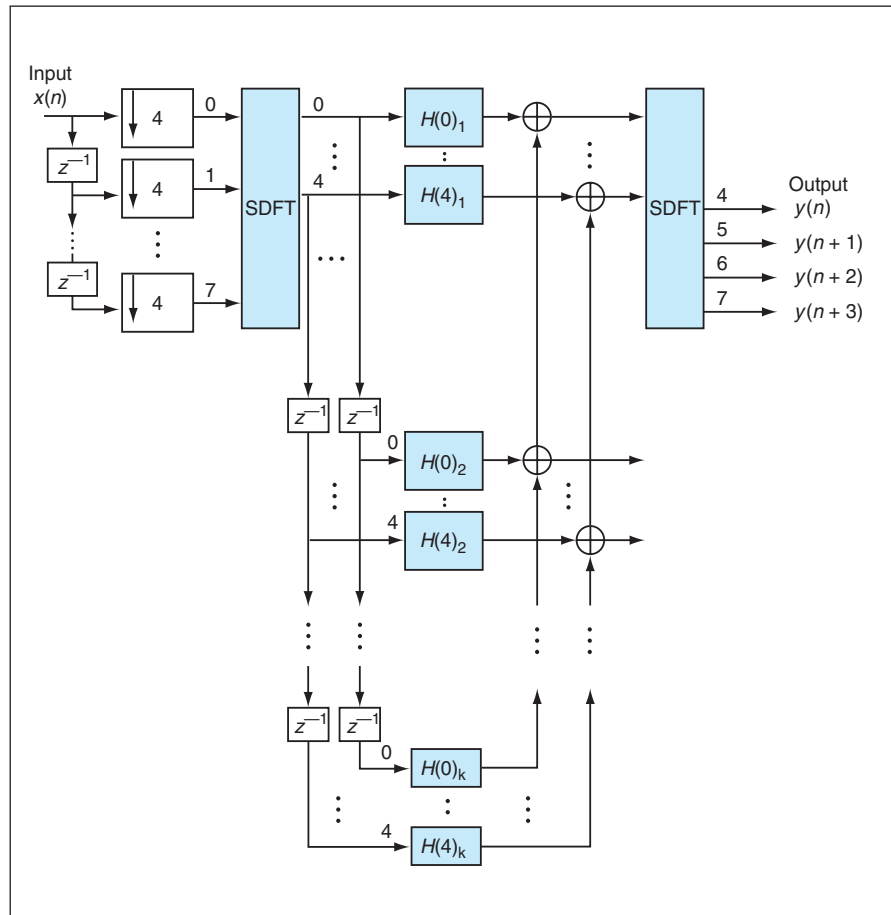
- Certain processing architectures are arbitrarily scalable, such that filter orders and reductions in processing rates can be chosen independently of each other without altering FFT-IFFT lengths. While this is generally true in time-domain approaches, it has not, heretofore, been the case in frequency-domain approaches without altering FFT-IFFT lengths.
- Under many circumstances using the frequency-domain approach entails fewer computations per filtered output than time-domain counterparts. Therefore, fewer transistors and/or lower power consumption may result from such an implementation.
- The ability to manipulate phase and frequency bands in the frequency-domain approach may have advantages

in some systems employing time-varying predistortion filtering.

The theory and design rules incorporate new and simple subconvolution filtering methods as well as prior developments in discrete-time signal processing, multi-rate filtering, and general linear-systems theory. The theoretical derivation begins with the subdivision of a time-domain convolution into a number of subconvolutions. The subconvolutions are recast as combinations of subsampling (decimation) in parallel, variously delayed streams to obtain parallel-processable pairs of specialized discrete Fourier transforms (SDFTs) and their inverses (SIDFTs) (see figure). The specialization lies in the elimination of redundant and unnecessary

computations by (1) skipping over terms that are known to be identically zero and (2) exploiting the fact that in the frequency-domain representation of the desired filter response, each negative-frequency component is the complex conjugate of the corresponding positive-frequency component. Additional simplifications are made on the basis of the (up-sampled) nature of the input signal. Modularization and expanded parallel operation can be effected by splitting the filtering across multiple blocks.

This work was done by Andrew A. Gray of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-30186



The Subconvolution Filtering Architecture represented by this diagram is an example for a case of decimation by 4 (1/4th rate processing) and a pulse-shaping filter of order k . The symbol " $\downarrow 4$ " represents decimation by 4, the H quantities are frequency-domain filter coefficients, and the z^{-1} signifies a delay equal to one input sample period.

High-Fidelity Piezoelectric Audio Device

The same device can generate sound or tactile, inaudible vibrations.

Langley Research Center, Hampton, Virginia

ModalMax is a very innovative means of harnessing the vibration of a piezoelectric actuator to produce an energy efficient low-profile device with high-bandwidth high-fidelity audio response. The piezoelectric audio device outperforms many commercially avail-

able speakers made using speaker cones. The piezoelectric device weighs substantially less (4 g) than the speaker cones which use magnets (10 g). ModalMax devices have extreme fabrication simplicity. The entire audio device is fabricated by lamination. The simplicity of the design lends itself to lower cost. The piezoelectric audio device can be used without its acoustic chambers and thereby resulting in a very low thickness of 0.023 in. (0.58 mm). The piezoelectric audio device can be completely encapsulated, which makes it very attractive for use in wet environments. Encapsulation does not significantly alter the audio response. Its small size (see Figure 1) is applica-

ble to many consumer electronic products, such as pagers, portable radios, headphones, laptop computers, computer monitors, toys, and electronic games. The audio device can also be used in automobile or aircraft sound systems.

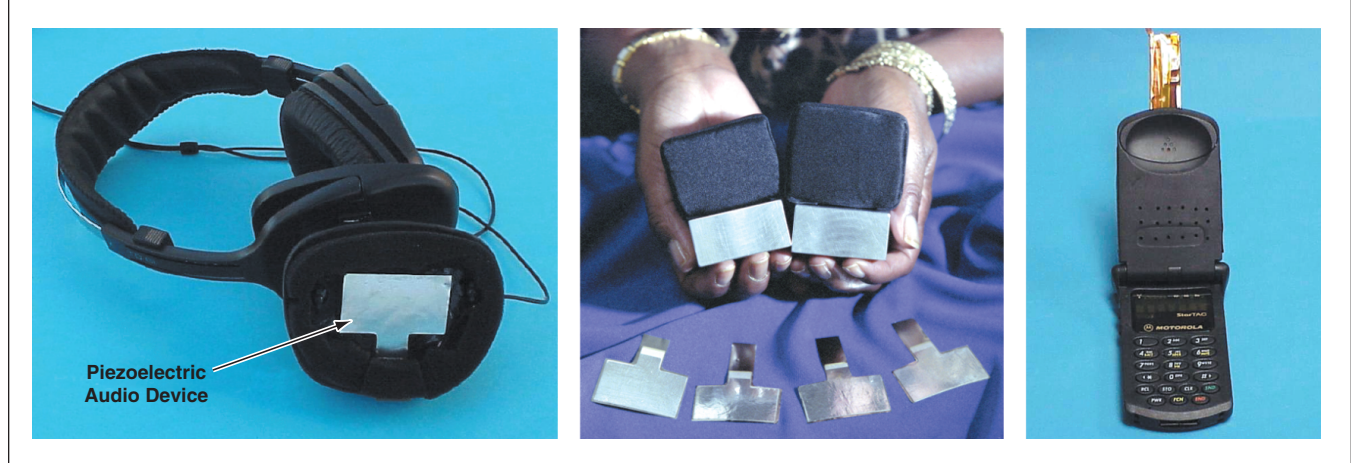


Figure 1. Piezoelectric Audio Devices can be mounted in headphones, used as speakers, and used inside a cell phone.

ble to many consumer electronic products, such as pagers, portable radios, headphones, laptop computers, computer monitors, toys, and electronic games. The audio device can also be used in automobile or aircraft sound systems.

The result of using the ModalMax techniques is a piezoelectric audio device with the audio response shown in Figure 2. At 1 cm (sufficient distance for headphones use), the response is 93 ± 5 dB for 600–5,000 Hz, (± 4 dB for response greater than 1 kHz). The de-

vice impedance decreases with frequency (3,500 ohms at 100 Hz, 83 ohms at 5 kHz and 43 ohms at 10 kHz). ModalMax consists of four methods used to produce high-quality sound from a piezoelectric actuator.

- *Mapping Vibration Topography* is the first method used to enhance audio output of piezoelectric devices. During vibration, the cyclic surface deformation produces out-of-plane displacements, the reciprocating strokes of which are similar to a piston. Deformation topography that occurs during vibration is measured using a laser vibrometer. The topography is used to identify all out-of-plane displacement lines and points having amplitudes sufficient for driving acoustic devices.
- *Tailoring Vibration Response* is the second method used to enhance piezoelectric audio output. The center photo in Figure 1 shows a piezoelectric actuator that has been developed to have numerous natural frequencies with high out-of-plane displacement amplitudes. The device has a "T" planform (i.e., throat and crossbar). The throat has a low torsion and bending stiffness; yet, can sustain

from the mounting line. The out-of-plane displacements for the 743 Hz and 426 Hz natural frequencies exceed 0.03 in. (0.76 mm). The displacement at the 977 Hz natural frequency can be seen with the naked eye.

- *Tailoring Damping Distribution* is the third method used and consists of strategically locating damping material on the piezoelectric device. The damping material makes the audio response quickly decay after a stimulus is removed. Eliminating persistent vibration reduces audio distortion. The complete audio response decays in approximately 3.7 ms.
- *Applying Acoustic Chambers* to one or more out-of-plane displacement lines identified from mapping is the fourth method of enhancing audio output. Locating multiple chambers on the piezoelectric-device surface makes it possible for a single actuator to drive numerous sound sources. Typical audio devices use a single driver (e.g., speaker cone driven by magnet) to produce a single sound source. Each acoustic chamber is formed as a cylinder with its bottom surface removed. The top surface has an orifice. When affixed to the

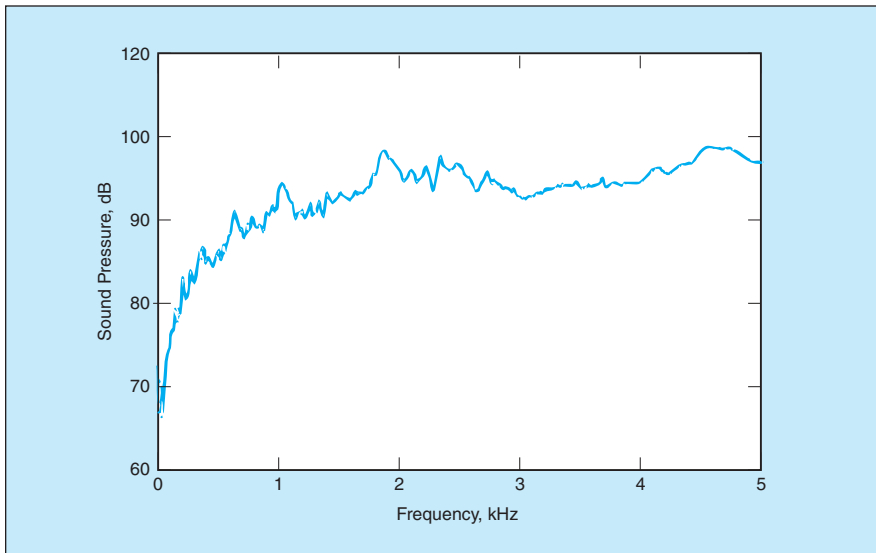


Figure 2. An **Audio Response** is shown for a piezoelectric-audio-device sound-pressure level measured at 1 cm without any sound enclosure using ± 14 V.

surface of the piezoelectric actuator, a resonating chamber similar to a Helmholtz chamber is formed.

*This work was done by Stanley E. Woodard, Robert L. Fox, and Robert G. Bryant of **Langley Research Center**. For further information, write to R. P. Turcotte, NASA Langley Research Center: postal address 3 Langley Boulevard, Mail Stop 200, Hampton, VA 23681-2199; telephone (757) 864-8881; fax (757) 864-8314; e-mail address r.p.turcotte@larc.nasa.gov.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center; (757) 864-3521. Refer to LAR-15959.

Photovoltaic Power Station With Ultracapacitors for Storage

Ultracapacitors offer advantages over batteries in this application.

John H. Glenn Research Center, Cleveland, Ohio

The figure depicts a solar photovoltaic power station in which ultracapacitors, rather than batteries, are used to store energy. Developments in the semiconductor industry have reduced the cost and increased the attainable efficiency of commercially available photovoltaic panels; as a result, photovoltaic generation of power for diverse applications has become practical. Photovoltaic generation can provide electric power in remote locations where electric power would otherwise not be available. Photovoltaic generation can also afford independence from utility systems. Applications include supplying power to scientific instruments and medical equipment in isolated geographical regions.

The reasons for choosing ultracapacitors instead of batteries in this power station are the following:

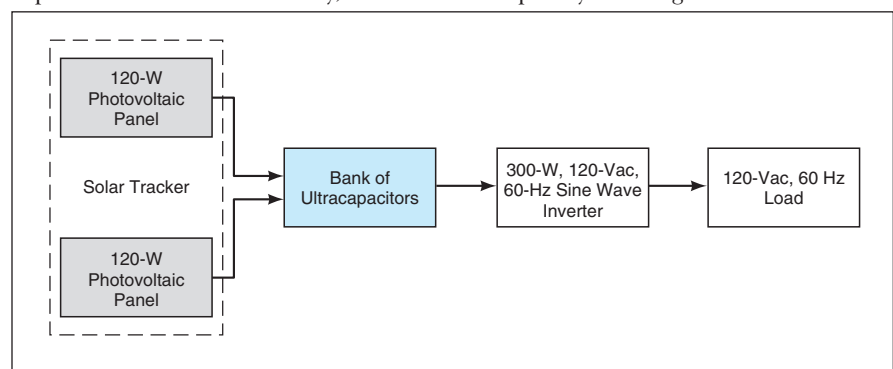
- Batteries are not particularly suitable for storing energy generated in photovoltaic power systems. Batteries must be kept adequately charged, and are not permitted to be completely discharged. The variability of available sunlight makes it difficult to satisfy this requirement.
- Batteries must be sized to accommodate peak load currents, which are usually much greater than average load currents.

- Batteries have rather short cycle lives and their internal chemical reactions cause deterioration over time.
- Batteries perform poorly at low temperatures.
- Ultracapacitors make it possible to overcome most of the aforementioned disadvantages of batteries.

The ultracapacitors in this power station are electrochemical units. Because these capacitors contain large-surface-area electrodes with very small interelectrode gaps, they have large volumetric capacitances. Capacitors can have cycle lives that are extremely long, relative to those of batteries; indeed, it may never become necessary to replace capacitors. The longevity of capacitors increases reliability, reduces

life-of-system costs, and reduces adverse environmental effects. The longevity of capacitors is especially desirable for photovoltaic power systems, which are kept in service continuously for many years.

The power densities of capacitors exceed those of batteries. Therefore, high power can be drawn as needed and then capacitors can be recharged very quickly in preparation for the next high power demand. Capacitors have excellent low-temperature characteristics, continue to function without need for maintenance, and perform consistently over time. In addition, capacitors are conducive to safety in that it is easy to discharge them and they can be left completely discharged.



This **Photovoltaic Power Station** utilizes ultracapacitors (instead of batteries) as energy-storage devices.

The present power station includes two 5- by 2-ft (1.5- by 0.6-m) all-weather photovoltaic panels, each rated at a power of 120 W. The photovoltaic panels are connected in parallel to provide up to 240 W at a potential of 16.9 V. The photovoltaic panels are mounted on a solar tracker for tracking the path of the Sun to maintain efficiency (at up to 50 percent more than the attainable efficiency of panels mounted in a fixed orientation). The tracker is a thermally actuated device: it exploits solar heating and consequent differential thermal expansion to change the orientation of the panels.

The outputs of the photovoltaic panels are sent to the bank of ultracapacitors for energy storage. Capacitors are excellent for this application in that a complex voltage regulator is not needed, as it would be if batteries were used. The ultracapacitors can tolerate voltage variations up to their maximum voltage rating. The ultracapacitors feed a 300-W, 60-Hz sine-wave inverter for powering various ac loads. A sine-wave inverter was chosen to minimize the generation of noise and to supply clean power to the load.

Additional photovoltaic panels and ultracapacitors can easily be added to

satisfy an increased power demand. The photovoltaic panels and ultracapacitors in this power station have a minimum expected life of 25 years.

*This work was done by Dennis J. Eichenberg, John S. Kolacz, Richard F. Soltis, and Paul F. Tavernelli of **Glenn Research Center**.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17177.

Time Analyzer For Time Synchronization and Monitor of the Deep Space Network

A software package has been developed to measure, monitor, and archive the performance of timing signals distributed in the NASA Deep Space Network. Timing signals are generated from a central master clock and distributed to over 100 users at distances up to 30 kilometers. The time offset due to internal distribution delays and time jitter with respect to the central master clock are critical for successful spacecraft navigation, radio science, and very long baseline interferometry (VLBI) applications. The instrument controller and operator interface software is written in LabView and runs on the Linux operating system. The software controls a commercial multiplexer to switch 120 separate timing signals to measure offset and jitter with a time-interval counter referenced to the master clock. The offset of each channel is displayed in histogram form, and "out of specification" alarms are sent to a central complex monitor and control system. At any time, the measurement cycle of 120 signals can be interrupted for diagnostic tests on an individual channel. The instrument also routinely monitors and archives the long-term stability of all frequency standards or any other 1-pps source compared against the master clock. All data is stored and made available for remote access via network connection.

This program was developed by Steven Cole, Jorge Gonzalez, Jr., Malcolm Cathoun, and Robert Tjoelker 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 Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30483.

Program for Computing Albedo

Simple Thermal Environment Model (STEM) is a FORTRAN-based computer program that provides engineering estimates of top-of-atmosphere albedo and outgoing long-wave radiation (OLR) for use in analyzing thermal loads on spacecraft near Earth. The thermal environment of a spacecraft is represented in

STEM as consisting of direct solar radiation; short-wave radiation reflected by the atmosphere of the Earth, as characterized in terms of the albedo of the Earth; and OLR emitted by the atmosphere of the Earth. STEM can also address effects of heat loads internal to a spacecraft. Novel features of STEM include (1) the use of Earth albedo and OLR information based on time series of measurements by Earth Radiation Budget Experiment satellites in orbit; (2) the ability to address thermal time constants of spacecraft systems by use of albedo and OLR values representing averages over a range of averaging times; and (3) the ability to address effects, on albedo and OLR values, of satellite orbital inclination, the angle between the plane of a spacecraft orbit and the line between the centers of the Earth and Sun, the solar zenith angle, and latitude.

This program was written by Carl G. (Jere) Justus of Computer Sciences Corp. for Marshall Space Flight Center. Further information is contained in a TSP (see page 1). MFS-31728

Integrated Software for Analyzing Designs of Launch Vehicles

Launch Vehicle Analysis Tool (LVA) is a computer program for preliminary design structural analysis of launch vehicles. Before LVA was developed, in order to analyze the structure of a launch vehicle, it was necessary to estimate its weight, feed this estimate into a program to obtain pre-launch and flight loads, then feed these loads into structural and thermal analysis programs to obtain a second weight estimate. If the first and second weight estimates differed, it was necessary to reiterate these analyses until the solution converged. This process generally took six to twelve person-months of effort. LVA incorporates text to structural layout converter, configuration drawing, mass properties generation, pre-launch and flight loads analysis, loads output plotting, direct solution structural analysis, and thermal analysis subprograms. These subprograms are integrated in LVA so that solutions can be iterated automatically. LVA incorporates expert-system software that makes fundamental design decisions without intervention by the user. It also includes unique algorithms based

on extensive research. The total integration of analysis modules drastically reduces the need for interaction with the user. A typical solution can be obtained in 30 to 60 minutes. Subsequent runs can be done in less than two minutes.

This program was written by Alan D. Philips of Marshall Space Flight Center. LVA contains code modules previously written by Carl E. Colley while he was a NASA civil servant. For further information, contact the Marshall Commercial Technology Office at (256) 544-2615. MFS-31694

Abstract-Reasoning Software for Coordinating Multiple Agents

A computer program for scheduling the activities of multiple agents that share limited resources has been incorporated into the Automated Scheduling and Planning Environment (ASPEN) software system, aspects of which have been reported in several previous NASA Tech Briefs articles. In the original intended application, the agents would be multiple spacecraft and/or robotic vehicles engaged in scientific exploration of distant planets. The program could also be used on Earth in such diverse settings as production lines and military maneuvers. This program includes a planning/scheduling subprogram of the iterative repair type that reasons about the activities of multiple agents at abstract levels in order to greatly improve the scheduling of their use of shared resources. The program summarizes the information about the constraints on, and resource requirements of, abstract activities on the basis of the constraints and requirements that pertain to their potential refinements (decomposition into less-abstract and ultimately to primitive activities). The advantage of reasoning about summary information is that time needed to find consistent schedules is exponentially smaller than the time that would be needed for reasoning about the same tasks at the primitive level.

This program was written by Bradley Clement, Anthony Barrett, Gregg Rabideau, and Russell Knight for 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 Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30340.

⊕ Software Searches for Better Spacecraft-Navigation Models

ADAPT is a computer program that searches for better mathematical models for spacecraft navigation. The task of tuning trajectory-determination models for interplanetary navigation is complex, requiring an intensive search of multiple dynamical and nondynamical models that yield trajectory solutions with minimal errors. By automating the search, ADAPT eases the task of human analysts and enables them to consider wider ranges of potential solutions. ADAPT uses genetic algorithms to search a range of relevant parameters in a user-selected design space to arrive at values for those parameters that best fit the measured spacecraft-tracking data. The user's guide for ADAPT reviews the theoretical basis of the program and presents two example applications. One example is that of selecting a solar-radiation model for the Mars Pathfinder (MPF) mission using MPF tracking data and an extended Kalman filter from prior spacecraft-navigation software. The second example is of the use of tracking data from the Stardust

spacecraft mission combined with a pseudo-epoch-state batch filter and an empirical small-forces model to find improved impulse models for use during Stardust attitude adjustments.

This program was written by Todd Ely of Caltech and William Crossley of Purdue University 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 Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30552.

🔍 Software for Partly Automated Recognition of Targets

The Feature Analyst is a computer program for assisted (partially automated) recognition of targets in images. This program was developed to accelerate the processing of high-resolution satellite image data for incorporation into geographic information systems (GIS). This program creates an advanced user interface that embeds proprietary machine-learning algorithms in commercial image-processing and GIS software. A human analyst provides sam-

ples of target features from multiple sets of data, then the software develops a data-fusion model that automatically extracts the remaining features from selected sets of data. The program thus leverages the natural ability of humans to recognize objects in complex scenes, without requiring the user to explain the human visual recognition process by means of lengthy software. Two major subprograms are the reactive agent and the thinking agent. The reactive agent strives to quickly learn the user's tendencies while the user is selecting targets and to increase the user's productivity by immediately suggesting the next set of pixels that the user may wish to select. The thinking agent utilizes all available resources, taking as much time as needed, to produce the most accurate autonomous feature-extraction model possible.

This program was written by David Opitz, Stuart Blundell, William Bain, Matthew Morris, Ian Carlson, and Mark Mangrich of Visual Learning Systems, Inc., for Stennis Space Center. For further information, contact the Stennis Commercial Technology Office at (228) 688-1929. SSC-00166



Antistatic Polycarbonate/Copper Oxide Composite

Surface resistance lies in the desired range.

Lyndon B. Johnson Space Center, Houston, Texas

A composite material consisting of polycarbonate filled with copper oxide has been found to be suitable as an antistatic material. This material was developed to satisfy a requirement for an antistatic material that has a mass density less than that of aluminum and that exhibits an acceptably low level of outgassing in a vacuum.

Polycarbonate was chosen as the matrix material because it was known to satisfy the low-outgassing requirement. Copper oxide was chosen as the electrically conductive filler material in order to obtain surface resistivity in the desired static-electricity-dissipation range

between about 10^5 and 10^{11} ohms per square. (Materials with lower surface resistivities are regarded as conductive; materials with surface resistivities greater than about 10^{12} ohms per square are regarded as insulative and thus not suitable for protecting items sensitive to electrostatic discharge.)

A specimen of the copper oxide-filled carbonate material was subjected to a parallel-bar-contact surface-resistivity test and a static-discharge test at a temperature of 22 °C and relative humidity of 50 percent. The specimen was found to have a surface resistivity of 10^9

ohms per square on its rough side and 10^{10} ohms per square on its smooth side. The time for discharging from a potential of 5,000 V to 500 V was measured to be about 0.1 s, and there was no measurable charge left after 5 s. These measured characteristics are well within the acceptable ranges for an antistatic material according to applicable NASA and military standards.

This work was done by Michael Kovich of Lockheed Martin Corp. and George R. Rowland, Jr., of Hernandez Engineering Inc. for Johnson Space Center. Further information is contained in a TSP (see page 1). MSC-23356

Better VPS Fabrication of Crucibles and Furnace Cartridges

The choice of alloy composition and processing parameters is important.

Marshall Space Flight Center, Alabama

An experimental investigation has shown that by (1) vacuum plasma spraying (VPS) of suitable refractory metal alloys on graphite mandrels, and then (2) heat-treating the VPS alloy deposits under suitable conditions, it is possible to fabricate improved crucibles and furnace cartridges that could be used at maximum temperatures between 1,400 and 1,600 °C and that could withstand chemical attack by the materials to be heated in the crucibles and cartridges. Taken by itself, the basic concept of fabricating furnace cartridges by VPS of refractory materials onto graphite mandrels is not new; taken by itself, the basic concept of heat treatment of VPS deposits for use as other than furnace cartridges is also not new; however, prior to this investigation, experimental crucibles and furnace cartridges fabricated by VPS had not been heat treated and had been found to be relatively weak and brittle. Accordingly, the investigation was directed toward determining whether certain combinations of (1) refractory alloy compositions, (2) VPS parameters, and (3) heat-treatment parameters could result in VPS-

fabricated components with increased ductility.

The table describes five refractory metal alloys that were considered in this investigation. In each case, during vacuum plasma spraying, the alloy powder or corresponding mixture of elemental metal powders was delivered to a plasma gun by a flow of argon. The plasma gun was located in a vacuum chamber that

was evacuated and backfilled with argon at a low pressure. The plasma gun generated an argon/hydrogen plasma that melted the powder and projected it toward graphite mandrels, which were rotated so that the VPS deposits would form tubes. After plasma spraying, the tubes were removed from the mandrels.

Some of the VPS tubes were subjected to heat treatments based on current prac-

Alloy Composition, Weight Percentages	Supplied as Mixture of Elemental Powders (M) or as an Alloy Powder (A)
95.5 W, 3.5 Ni, 1.0 Fe	M
60 Mo, 40 Re	M
90 Ta, 10 W	M
75 W, 25 Re	M
99 Nb, 1 Zr	A

These Refractory Alloys were tested in experiments on fabrication by VPS and heat treatment.

tice in the sintering and annealing of conventional powder-metallurgy components. Each tube was packed with high-purity alumina sand to prevent slumping of the thin-walled tubes during heating. Hydrogen was used during the heat treatment of three of the alloys (60Mo/40Re, 75W/25Re, and 95.5W/3.5Ni/1.0Fe) to aid in densification and in the reduction of oxides. Both a liquid-phase sinter (LPS) and a solid-state sinter (SSS) were used on the 95.5W/3.5Ni/1.0Fe alloy. Hydrogen was not used during heat treatment of the 90Ta/10W and 99Nb/1Zr alloys because these alloys are susceptible to the formation of brittle hydrides; instead, these alloys were annealed in vacuum.

Standard metallurgical polishing techniques were used to prepare specimens of the as-sprayed and heat-treated tubes of each alloy. These specimens were then examined in the as-polished and etched conditions, by use of an optical microscope. Quantitative microscopy was used to determine the densities of the specimens. Helium leak tests were performed on the as-sprayed and heat-treated specimens to determine whether any interconnected porosity was open to the surfaces. Some room-temperature compression tests were performed on heat-treated specimens to determine whether there were any improvements in mechanical properties.

The SSS and LPS heat treatments were found to effect significant increases in toughness and ductility of the 95.5W/3.5Ni/1.0Fe alloy, and to result in cartridge helium-leak rates of about 10^{-8} cm³/s — well below the maximum allowable rate of 10^{-6} cm³/s. For the other alloys and heat treatments investigated, there was a mix of favorable and unfavorable findings.

*This work was done by Richard R. Holmes and Frank R. Zimmerman of Marshall Space Flight Center and J. Scott O'Dell and Timothy N. McKechnie of Plasma Processes Inc. Further information is contained in a TSP (see page 1).
MFS-31301*

Burn-Resistant, Strong Metal-Matrix Composites

Ceramic particulate fillers increase burn resistances and specific strengths of metals.

Lyndon B. Johnson Space Center, Houston, Texas

Ceramic particulate fillers increase the specific strengths and burn resistances of metals: This is the conclusion drawn by researchers at Johnson Space Center's White Sands Test Facility. The researchers had theorized that the inclusion of ceramic particles in metal tools and other metal objects used in oxygen-rich atmospheres (e.g., in hyperbaric chambers and spacecraft) could reduce the risk of fire and the consequent injury or death of personnel. In such atmospheres, metal objects act as ignition sources, creating fire hazards. However, not all metals are equally hazardous: some are more burn-resistant than others are. It was the researchers' purpose to identify a burn-resistant, high-specific-strength ceramic-particle/metal-matrix composite that could be used in oxygen-rich atmospheres.

The researchers studied several metals. Nickel and cobalt alloys exhibit high burn resistances and are dense (ranging from 7 to 9 g/cm³). For a space-flight or industrial application in which weight is a primary concern, the

increased weight that must be incurred to obtain flame resistance may be unacceptable. Aluminum and titanium are sufficiently less dense that they can satisfy most weight requirements, but they are much more likely to combust in oxygen-enriched atmospheres: In pure oxygen, aluminum is flammable at a pressure of 25 psia (absolute pressure \approx 170 kPa) and titanium is flammable below 2 psia (absolute pressure \approx 14 kPa).

The researchers next turned to ceramics, which they knew do not act as ignition sources. Unlike metals, ceramics are naturally burn-resistant. Unfortunately, they also exhibit low fracture toughnesses. Because a typical ceramic lacks the malleability, durability, and strength of a metal, ceramics are seldom used in outer-space and industrial environments. The researchers theorized that a ceramic-particle/metal-matrix composite might provide the best of both classes of materials: the burn resistance of the ceramic and the tensile strength of the metal. They demonstrated that when incorporated into

such low-burn-resistance metals as aluminum and titanium, ceramic particles increase the burn resistances of the metals by absorbing heat of combustion. In the case of such high-burn-resistance metals as nickel and copper, it was demonstrated that ceramic particulate fillers increase specific strengths while maintaining burn resistances.

Preliminary data from combustion tests indicate that an A339 aluminum alloy filled with 20 volume percent of silicon carbide is burn-resistant at pressures up to 1,200 psia (absolute pressure \approx 8.3 MPa) — that is, it has 48 times the threshold pressure of unfilled aluminum. The data show that of all the composites tested to date, this composite has the greatest burn resistance and greatest specific strength and is the best candidate for use in oxygen-enriched atmospheres.

*This work was done by Joel M. Stoltzfus of Johnson Space Center and Moti J. Tayal of Rockwell International Corp. For further information, contact the Johnson Commercial Technology Office at (281) 483-3809.
MSC-22676*



Self-Deployable Spring-Strip Booms

These structures can be stowed compactly with small forces and become rigid once deployed.

NASA's Jet Propulsion Laboratory, Pasadena, California

Booms and other structures consisting mainly of thin spring strips are undergoing development. These structures are designed to be lightweight, to be compactly stowable, and to be capable of springing to stable configurations at full extension once released from stowage. Conceived for use as self-deploying structures in outer space, portable structures of this type may also be useful on Earth in applications in which there are requirements for light weight and small transportation volume.

The elements common to these structures are spring strips with curved cross sections — similar to spring strips of the type commonly used as compactly stowable carpenters' measuring tapes. These structures exploit the nonlinear mechanical properties of such tapes, namely (1) strong resistance to axial buckling while they are straight and (2) ease with which they can be wound into compact rolls once they have been initially bent. For a structure that contains multiple such strips, the net effect of the combined nonlinear characteristics is the following:

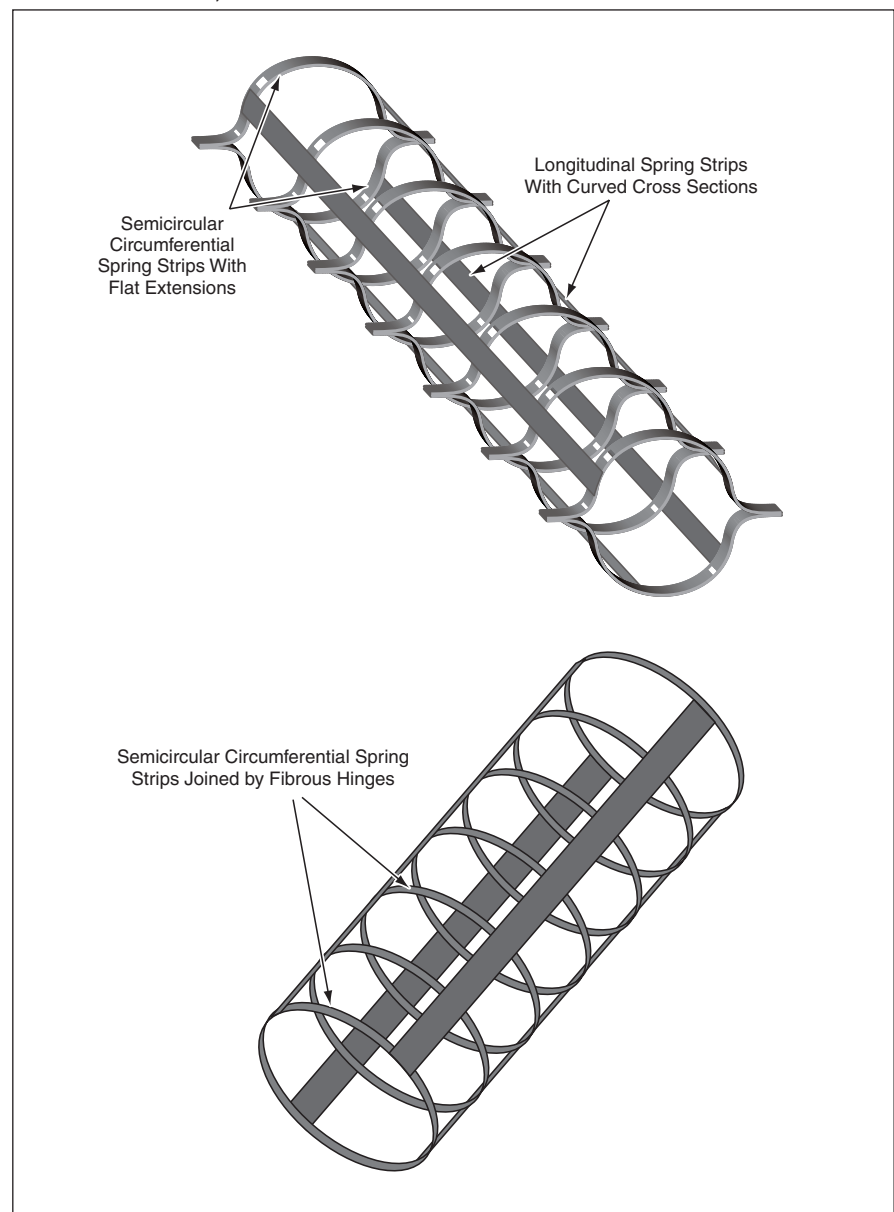
- When at full extension, the structure is in a stable state, in which it is rigid and strong.
- When stowed compactly, the structure is in a state that is semistable in the sense that only a small force is needed to restrain the structure against deployment.
- The strain energy stored in the spring strips during compaction is sufficient to deploy the structure to full extension when the restraint is removed.

The figure depicts two of several boom designs that have been investigated thus far. One design calls for several longitudinal spring strips with curved cross sections as described above, connected at intervals by semicircular circumferential spring strips with flat extensions. The main advantage of this design is relative strength; the main disadvantages are the additional weight and volume of the flat extensions and the potential for motion of the flat extensions to cause damage during deployment.

Another design features semicircular circumferential spring strips joined by fibrous hinges. The main disadvantage of this design is less strength, relative to the design described above; the main advantages are less weight and volume as well as greater safety during deployment. Still other designs feature, variously, circumferential

spring strips with self-locking hinges, and deployment control devices to reduce deployment speeds.

This work was done by Houfei Fang, Michael Lou, and Nathan Palmer of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-30175



Spring-Strip Booms are made of longitudinal spring strips with curved cross sections (similar to carpenters' measuring tapes) connected with circumferential spring strips.

Explosion Welding for Hermetic Containerization

There is no need to decontaminate the outside of the container.

NASA's Jet Propulsion Laboratory, Pasadena, California

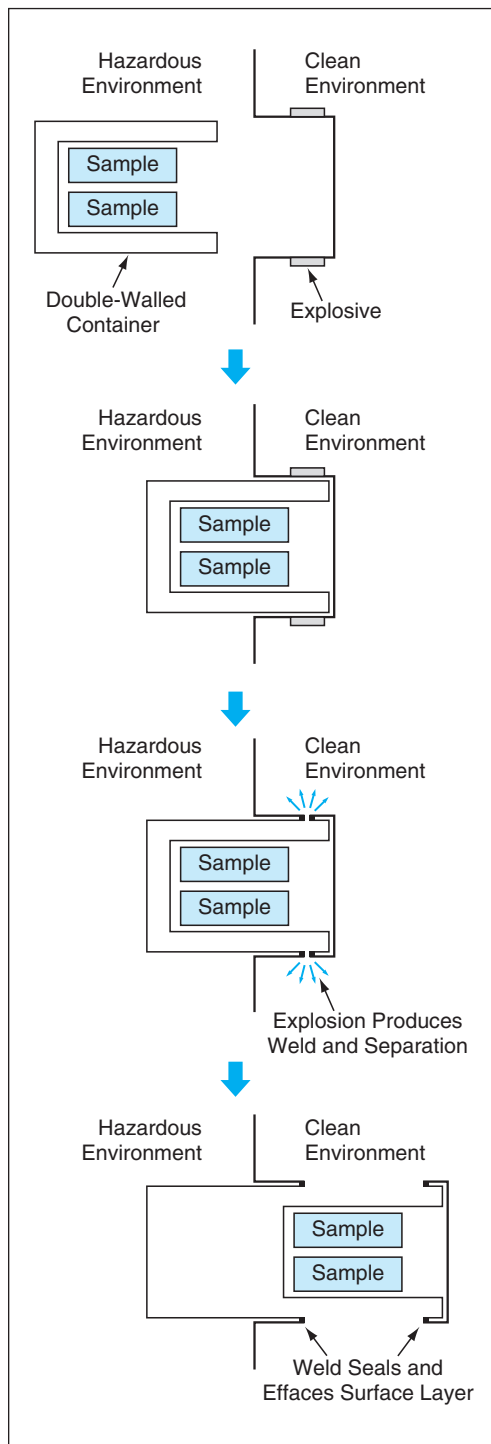


Figure 1. The **Explosion Seals the Samples** in the container while simultaneously excluding previous exterior container contamination from the clean environment.

A container designed for storing samples of hazardous material features a double wall, part of which is sacrificed during an explosion-welding process in which the container is sealed and transferred to a clean environment. The major advantage of this container sealing process is that once the samples have been sealed inside, the outer wall of what remains of the container is a clean surface that has not come into contact with the environment from which the samples were taken. Thus, there is no need to devise a decontamination process capable of mitigating all hazards that might be posed by unanticipated radioactive, chemical, and/or biological contamination of the outside of the container. The container sealing method was originally intended to be used to return samples from Mars to Earth, but it could also be used to store samples of hazardous ma-

terials, without the need to decontaminate its outer surface.

Figure 1 depicts the process stages. In its initial double-wall form, the volume between the walls is isolated from the environment; in other words, the outer wall (which is later sacrificed) initially serves to protect the inner container from contamination. The sample is placed inside the container through an opening at one end, then the container is placed into a transfer dock/lid. The surfaces that will be welded together under the explosive have been coated with a soft metallic sacrificial layer (see Figure 2). During the explosion, the sacrificial layer is ejected, and the container walls are welded together, creating a strong metallic seal. The inner container is released during the same event and enters the clean environment.

This work was done by Benjamin Dolgin and Joseph Sanok of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1). NPO-20868

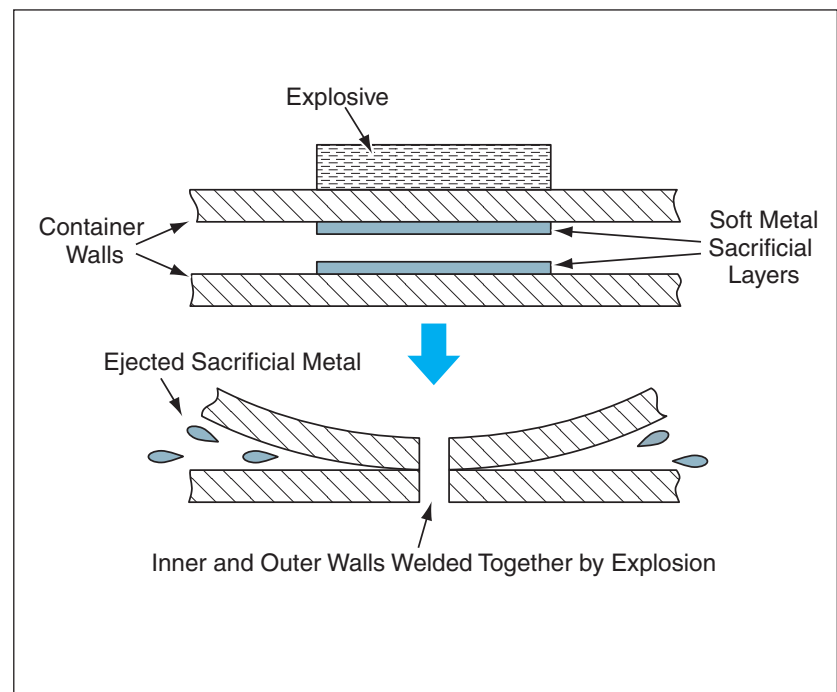


Figure 2. **Sacrificial Metal** is squeezed out, the container walls are cut, and the container walls are welded together on both sides of the cut.

Improved Process for Fabricating Carbon Nanotube Probes

Ames Research Center, Moffett Field, California

An improved process has been developed for the efficient fabrication of carbon nanotube probes for use in atomic-force microscopes (AFMs) and nanomanipulators. Relative to prior nanotube tip production processes, this process offers advantages in alignment of the nanotube on the cantilever and stability of the nanotube's attachment. A procedure has also been developed at Ames that effectively sharpens the multiwalled nanotube, which improves the resolution of the multiwalled nanotube probes and, combined with the greater stability of multiwalled nanotube probes, increases the effective resolution of these probes, making them comparable in resolution to single-walled carbon nanotube probes. The robust attachment de-

rived from this improved fabrication method and the natural strength and resiliency of the nanotube itself produces an AFM probe with an extremely long imaging lifetime. In a longevity test, a nanotube tip imaged a silicon nitride surface for 15 hours without measurable loss of resolution. In contrast, the resolution of conventional silicon probes noticeably begins to degrade within minutes. These carbon nanotube probes have many possible applications in the semiconductor industry, particularly as devices are approaching the nanometer scale and new atomic layer deposition techniques necessitate a higher resolution characterization technique. Previously at Ames, the use of nanotube probes has been demon-

strated for imaging photoresist patterns with high aspect ratio. In addition, these tips have been used to analyze Mars simulant dust grains, extremophile protein crystals, and DNA structure. This NASA technology is being commercialized through Convergent Science and Technology Inc. (www.con-sci-tech.com).

*This work was done by R. Stevens, C. Nguyen, A. Cassell, L. Delzeit, M. Meyyappan, and Jie Han of **Ames Research Center**. Further information is contained in a TSP (see page 1).*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Patent Counsel, Ames Research Center, (650) 604-5104. Refer to ARC-14611.



Automated Serial Sectioning for 3D Reconstruction

Automation increases speed and reduces uncertainty in alignment.

John H. Glenn Research Center, Cleveland, Ohio

Figure 1 depicts some aspects of an apparatus and method for automated serial sectioning of a specimen of a solder, aluminum, or other relatively soft opaque material. The apparatus includes a small milling machine (micromiller) that takes precise, shallow cuts (increments of depth as small as 1 μm) to expose successive sections. A microscope equipped with an electronic camera, mounted in a fixed position on the micromiller, takes pictures of the newly exposed specimen surface at each increment of depth. The images are digitized, and the resulting data are subsequently processed to reconstruct

three-dimensional (3D) features of the specimen.

The micromiller includes a three-axis (x,y,z) translation table. The specimen remains mounted on the translation table during all phases of the sectioning process, including etching and imaging in addition to milling. All motions of the table during the sectioning process take place under computer control. Thus, to index to the next increment of depth, the table is translated the corresponding short distance along the z-axis. The translation table is also used to move the specimen along the y-axis from the milling posi-

tion to an intermediate etching position, then to the imaging position, then back to the milling position for the next cut.

This method affords advantages over a related prior method in which a specimen was repeatedly cut on a micromiller, then dismantled, etched, photographed through a microscope, then remounted on the micromiller for the next cut. One advantage is elimination of much of the positioning uncertainty, and hence the uncertainty in registration of features seen at different depths, that arises from repeated mounting, dismantling, and photographing at a location different from the milling location.

Another advantage is automation of alignment of the images acquired at different depths. In the prior method, images were aligned, after they were recorded, in a procedure that was at least partly manual and hence time-consuming. In the present method, alignment is performed as an integral part of processing of the image data.

Inasmuch as tests have shown that there is no measurable undesired translation of the specimen along the x-axis, the alignment problem involves mainly compensating for any error in returning the specimen, on each cycle, to the same nominal y coordinate for imaging. Measurements have shown that the actual y coordinate used for imaging on a given section can deviate from the nominal position a distance of the order of 50 μm . In the present method, during imaging, the y coordinate of the specimen is measured by use of a linear variable-differential transformer (LVDT) accurate to within 0.5 μm . Then during processing of the image data as described in the next paragraph, the measured y coordinate of imaging position for each section is used as an offset to translate the image in y to the nominal position.

Once the image data from all sections have been recorded, they can be processed by readily available image-data-processing software, then combined to construct digital representa-

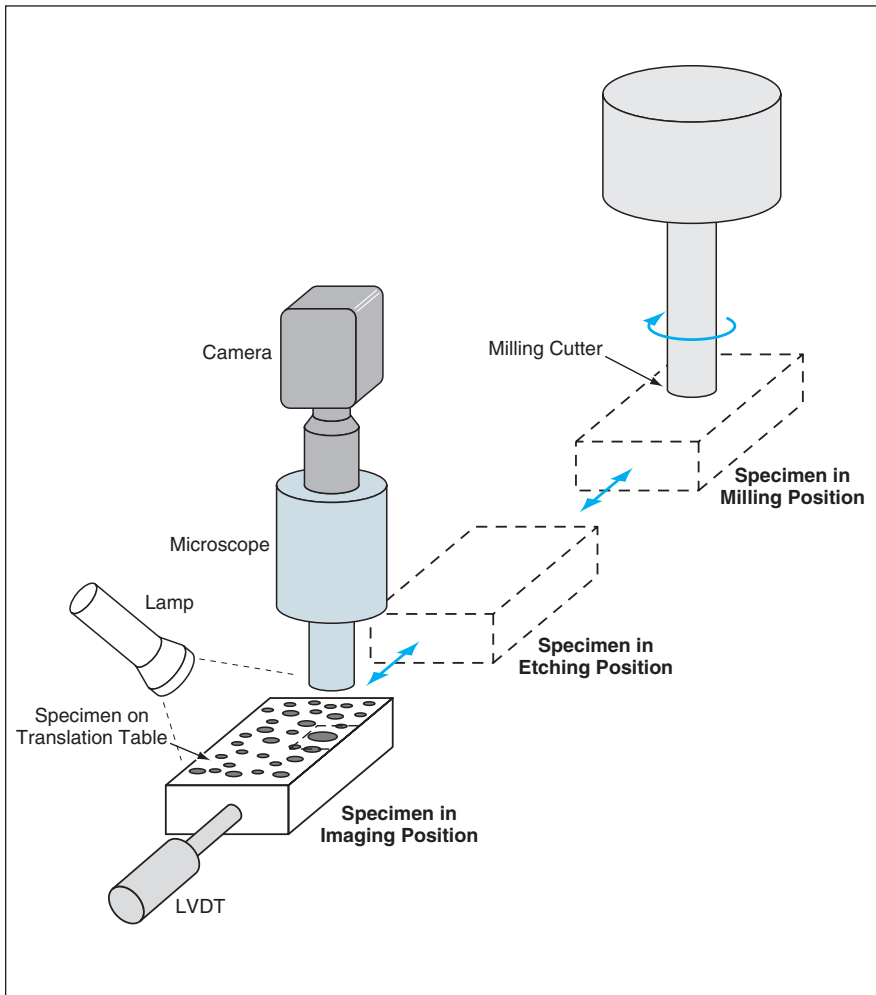


Figure 1. A Specimen on a Translation Table is moved along the y-axis among milling, etching, and imaging positions. With the help of the LVDT, the corrections for small y-axis misalignments of imaging positions can be made during processing of image data.

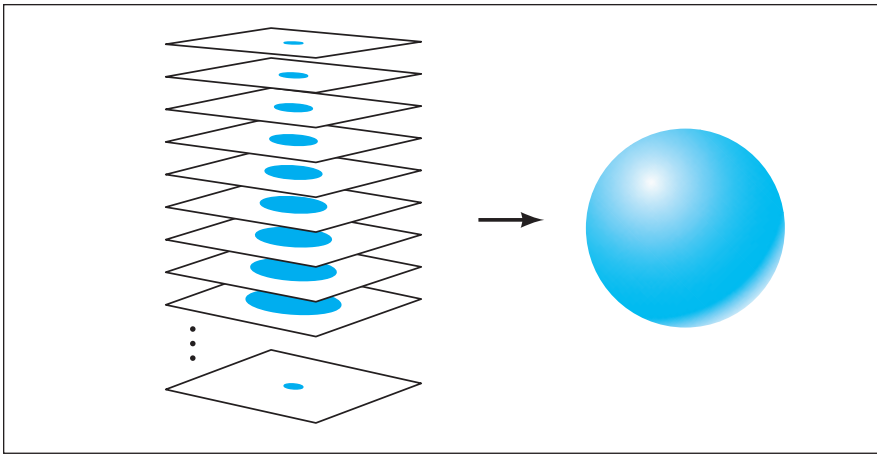


Figure 2. A **Three-Dimensional Feature** (in this case, a sphere of darker material) inside the specimen is reconstructed from cross sections taken sequentially at small increments of depth.

tions of three-dimensional features inside the specimen (see Figure 2). As a result of automation of the sectioning process, it is now possible to take about 20 sections per hour from given specimen, whereas previously, at most 10 sections could be taken in a day.

*This work was done by Jen Alkemper and Peter W. Voorhees of Northwestern University for **Glenn Research Center**. Further information is contained in a TSP (see page 1).*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4-8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-16820.



Parallel Subconvolution Filtering Architectures

These architectures are based on methods of vector processing and the discrete-Fourier-transform/inverse-discrete-Fourier-transform (DFT-IDFT) overlap-and-save method, combined with time-block separation of digital filters into frequency-domain subfilters implemented by use of sub-convolutions. The parallel-processing method implemented in these architectures enables the use of relatively small DFT-IDFT pairs, while filter tap lengths are theoretically unlimited. The size of a DFT-IDFT pair is determined by the desired reduction in processing rate,

rather than on the order of the filter that one seeks to implement. A report presents additional information on the parallel, discrete-time, sub-convolution filtering architectures that lie at the heart of the innovation described in “Modular, Parallel, Efficient Pulse-Shaping Filters” (NPO-30186) elsewhere in this issue of NASA Tech Briefs. The emphasis in the report is on those aspects of the underlying theory and design rules that promote computational efficiency, parallel processing at reduced data rates, and simplification of the designs of very-large-scale integrated (VLSI) circuits needed to implement high-order filters and correlators.

This work was done by Andrew A. Gray 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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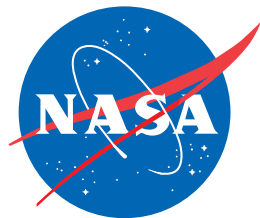
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Refer to NPO-30142, volume and number of this NASA Tech Briefs issue, and the page number.



National Aeronautics and
Space Administration