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Tech Briefs

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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lisa.l.lockyer@nasa.gov

Dryden Flight Research Center
Gregory Poteat
(661) 276-3872
greg.poteat@dfrc.nasa.gov

Goddard Space Flight Center
Nona Cheeks
(301) 286-5810
nona.k.cheeks@nasa.gov

Jet Propulsion Laboratory
Ken Wolfenbarger
(818) 354-3821
james.k.wolfenbarger@jpl.nasa.gov

Johnson Space Center
Michele Brekke
(281) 483-4614
michele.a.brekke@nasa.gov

Kennedy Space Center
Jim Aliberti
(321) 867-6224
Jim.Aliberti@nasa.gov

Langley Research Center
Martin Waszak
(757) 864-4052
martin.r.waszak@nasa.gov

Glenn Research Center
Robert Lawrence
(216) 433-2921
robert.f.lawrence@nasa.gov

Marshall Space Flight Center
Vernotto McMillan
(256) 544-2615
vernotto.mcmillan@msfc.nasa.gov

Stennis Space Center
John Bailey
(228) 688-1660
john.w.bailey@nasa.gov

Carl Ray, Program Executive
Small Business Innovation Research (SBIR) & Small Business Technology Transfer (STTR) Programs
(202) 358-4652
carl.g.ray@nasa.gov

Merle McKenzie
Innovative Partnerships Program Office
(202) 358-4652
merle.mckenzie-1@nasa.gov

TECH BRIEFS

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Technology Focus: Composites & Ceramics

Improving Thermomechanical Properties of SiC/SiC Composites

A heat treatment increases thermal conductivity and increases creep resistance.

John H. Glenn Research Center, Cleveland, Ohio

Today, a major thrust toward improving the thermomechanical properties of engine components lies in the development of fiber-reinforced silicon carbide matrix composite materials, including SiC-fiber/SiC-matrix composites. These materials are lighter in weight and capable of withstanding higher temperatures, relative to state-of-the-art metallic alloys and oxide-matrix composites for which maximum use temperatures are in the vicinity of 1,100 °C. In addition, the toughness or damage tolerance of the SiC-matrix composites is significantly greater than that of unreinforced silicon-based monolithic ceramics.

For successful application in advanced engine systems, the SiC-matrix composites should be able to withstand component service stresses and temperatures for the desired component lifetimes. Inasmuch as the high-temperature structural lives of ceramic materials are typically limited by creep-induced growth of flaws, a key property required of such composite materials is high resistance to creep under conditions of use. Also, the thermal conductivity of the materials should be as high as possible so as to minimize component thermal gradients and thermal stresses.

A state-of-the-art SiC-matrix composite is typically fabricated in a three-step process: (1) fabrication of a component-shaped architectural preform reinforced by thermally stable high-performance fibers, (2) chemical-vapor infiltration (CVI) of a fiber-coating material such as boron nitride (BN) into the preform, and (3) infiltration of an SiC-based matrix into the remaining porosity in the preform. Generally, the matrices of the highest-performing composites are fabricated by initial use of a CVI SiC matrix component that is typically more thermally stable and denser than matrix components formed by processes other than CVI. As such, the initial SiC matrix component made by CVI provides better environmental protection to the coated fibers embedded within it. Also, the denser CVI SiC imparts to the composite better resistance to propagation of cracks, enhanced thermal conductivity, and higher creep resistance.

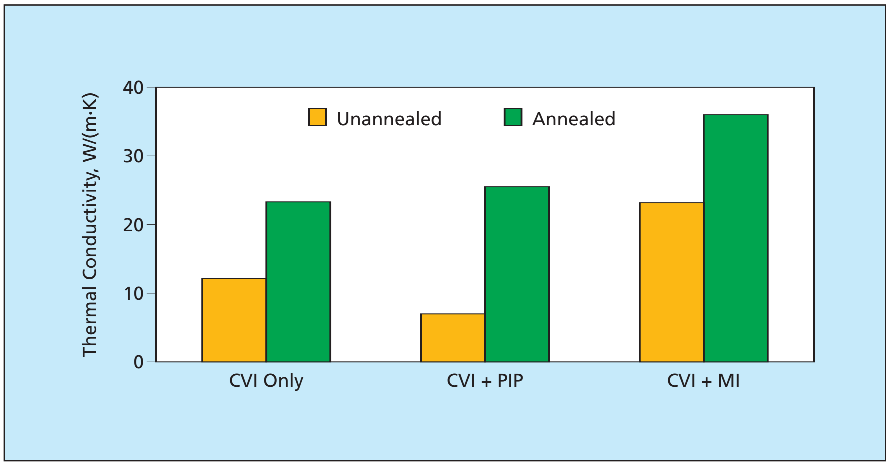


Figure 1. **Room-Temperature Thermal Conductivities** were measured on unannealed and annealed specimens of composite panels containing SiC matrices formed in various ways as described in the last paragraph of the main text.

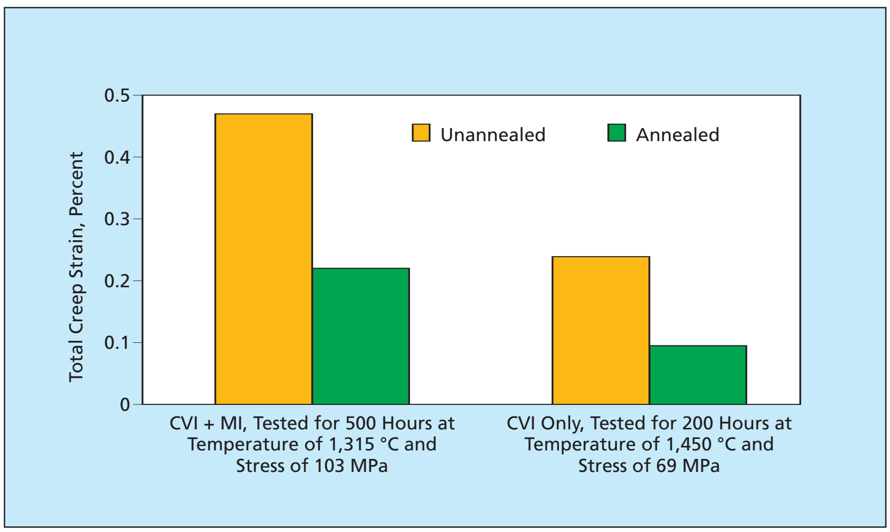


Figure 2. **Creep Strains** were measured on unannealed and annealed specimens of composite panels containing SiC matrices like two of those represented in Figure 1.

For adequate deposition of CVI SiC matrix material into a preform, it is typically necessary to perform the infiltration at a temperature below 1,100 °C. The use of an infiltration temperature in this range typically results in the formation of an SiC matrix that is fairly dense, but contains metastable atomic defects and is non-stoichiometric in that it contains a small excess of silicon. These defects typically exist at the matrix grain boundaries, where they can act as scatterers for thermal phonons and degrade matrix creep resistance by enhancing grain-boundary sliding.

In order to make it possible to eliminate these defects and improve the thermomechanical properties of ceramic composites that contain SiC matrices, researchers at Glenn Research Center (GRC) have developed a high-temperature heat or annealing treatment that can be performed after deposition of a

CVI SiC matrix into a fiber preform. Using (1) SiC fibers of a type developed by GRC and denoted "Sylramic-iBN" and (2) BN-based fiber coatings, which are both stable in their functions under the treatment conditions, the GRC researchers have observed minimal loss of strength in composite panels formed from two-dimensional architectural preforms and various contents of CVI SiC. More importantly, the NASA treatment significantly increased panel thermal conductivity and creep resistance, as indicated in Figures 1 and 2, respectively.

For the treated panels, the volume fractions of the fibers and BN coatings were about 36 percent and 8 percent, respectively. The first case represented in Figure 1 is that of a panel containing 50 volume percent SiC formed by CVI only. In the second case, the remaining open porosity in the 35-percent CVI SiC matrix was filled by a process denoted PIP, which involved repeated infiltration and pyrolysis of an SiC-yielding polymer (hybrid CVI + PIP). For the third case represented in Figure 1, the remaining open porosity in a 35-percent CVI SiC matrix was filled by a process that involved repeated melt infiltration (MI) of silicon at a temperature near 1,400 °C (hybrid CVI + MI). For the first two cases, the heat treatment was performed after final matrix formation; for the last case, the treatment was performed after CVI and before MI. In all cases, panel thermal conductivity was significantly increased by the NASA heat treatment. On an absolute scale, Figure 1 also shows the detrimental effect of trapped porosity on composite conductivity for the matrices formed by CVI only or by hybrid CVI + PIP, and the beneficial effects of the hybrid CVI + MI approach that more effectively fills the CVI SiC pores. However, Figure 2 shows that in the case of the matrix fully formed by CVI only, creep resistance and temperature capability were greater than in the case of the matrix formed by hybrid CVI + MI. Thus, because of their lack of elemental silicon, the long-term use temperature of the CVI-only matrix (as well as the hybrid CVI + PIP matrix) could exceed 1,400 °C, which is well above the long-term use temperature for panels containing matrices made by hybrid CVI + MI.

This work was done by James A. DiCarlo of **Glenn Research Center** *and Ramakrishna T. Bhatt of the Army Research Laboratory. Further information is contained in a TSP (see page 1).*

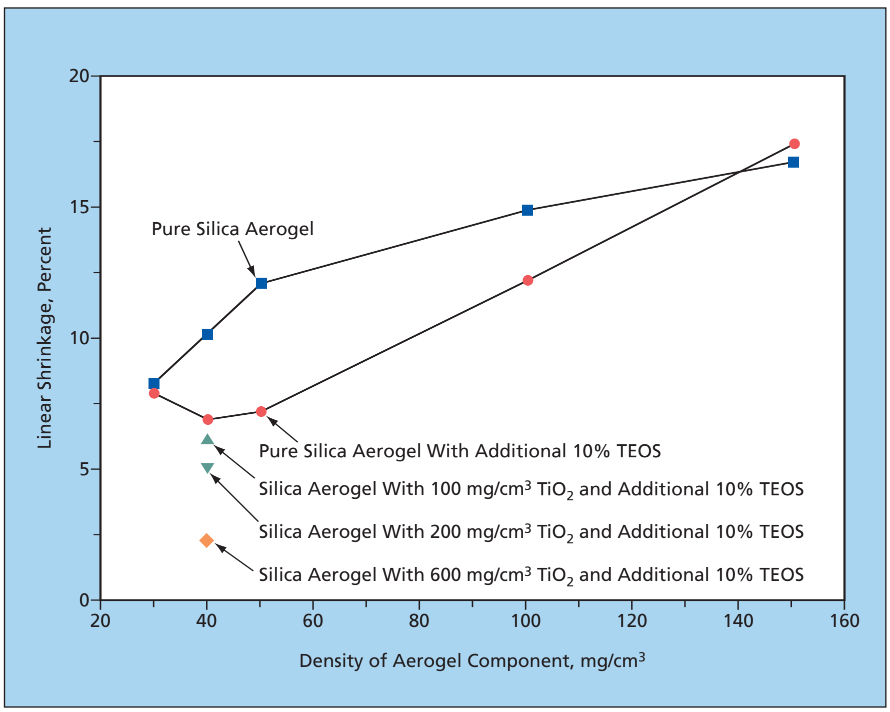
Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17595-1.

Aerogel/Particle Composites for Thermoelectric Devices

Shrinkage is reduced through addition of titania powder.

NASA's Jet Propulsion Laboratory, Pasadena, California

Optimizing solution chemistry and the addition of titania and fumed silica powder reduces shrinkage. These materials would serve to increase thermal efficiency by providing thermal insulation to suppress lateral heat leaks. They would also serve to prolong operational lifetime by suppressing sublimation of certain constituents of thermoelectric materials (e.g., sublimation of Sb from $CoSb_3$) at typical high operating temperatures. [The use of pure silica aerogels as cast-in-place thermal-insulation and sublimation-suppression materials was described in "Aerogels for Thermal Insulation of Thermoelectric Devices" (NPO-40630), *NASA Tech Briefs*, Vol. 30, No. 7 (July 2006), page 50.]



Shrinkages of Representative Aerogels of various densities and of aerogel/titania composites were measured.

A silica aerogel is synthesized in a sol-gel process that includes preparation of a silica sol, gelation of the sol, and drying of the gel in a solvent at a supercritical temperature and pressure. The utility of pure silica aerogel is diminished by a tendency to shrink (and, therefore, also to crack) during the gelation and supercritical-drying stages. Moreover, to increase suppression of sublimation, it is advantageous to make an aerogel having greater density, but shrinkage and cracking tend to increase with density.

A composite material of the type under investigation consists mostly of titania oxide powder particles and a small addition of fumed silica powder, which are mixed into the sol along with other ingredients prior to the gelation stage of processing. The silica aerogel and fumed silica act as a binder, gluing the titania particles together. It is believed that the addition of fumed silica stiffens the aerogel network and reduces shrinkage during the supercritical-drying stage. Minimization of shrinkage enables establishment of intimate contact between thermoelectric legs and the composite material, thereby maximizing the effectiveness of the material for thermal insulation and suppression of sublimation.

To some extent, the properties of the composite can be tailored via the proportions of titania and other ingredients. In particular (see figure), the addition of a suitably large proportion of titania (e.g., 0.6 g/cm^3) along with a 10-percent increase in the amount of tetraethylorthosilicate [TEOS (an ingredient of the sol)] to an aerogel component having a density 40 mg/cm^3 makes it possible to cast a high-average-density (>0.1 g/cm^3) aerogel/particle composite having low shrinkage (2.3 percent).

This work was done by Jong-Ah Paik, Jeffrey Sakamoto, and Steven Jones 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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JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-42031, volume and number of this NASA Tech Briefs *issue, and the page number.*

Patches for Repairing Ceramics and Ceramic-Matrix Composites

Patches are simply pressed in place, then heated.

Lyndon B. Johnson Space Center, Houston, Texas

Patches consisting mostly of ceramic fabrics impregnated with partially cured polymers and ceramic particles are being developed as means of repairing ceramics and ceramic-matrix composites (CMCs) that must withstand temperatures above the melting points of refractory metal alloys. These patches were conceived for use by space-suited, space-walking astronauts in repairing damaged space-shuttle leading edges: as such, these patches could be applied in the field, in relatively simple procedures, and with minimal requirements for specialized tools. These design characteristics also make the patches useful for repairing ceramics and CMCs in terrestrial settings.

In a typical patch as supplied to an astronaut or repair technician, the polymer would be in a tacky condition, denoted as an "A" stage, produced by partial polymerization of a monomeric liquid. The patch would be pressed against the ceramic or CMC object to be repaired, relying on the tackiness for temporary adhesion. The patch would then be bonded to the workpiece and cured by using a portable device to heat the polymer to a curing temperature above ambient temperature but well below the maximum operating temperature to which the workpiece is expected to be exposed. The patch would subsequently become pyrolized to a ceramic/glass condition upon initial exposure to the high operating temperature. In the original space-shuttle application, this exposure would be Earth-atmosphere-reentry heating to about 3,000 °F (about 1,600 °C).

Patch formulations for space-shuttle applications include SiC and ZrO_2 fabrics, a commercial SiC-based pre-ceramic polymer, and suitable proportions of both SiC and ZrO_2 particles having sizes of the order of 1 µm. These formulations have been tailored for the space-shuttle leading-edge material, atmospheric composition, and reentry temperature profile so as to enable repairs to survive re-entry heating with expected margin. Other formulations could be tailored for specific terrestrial applications.

This work was done by Peter A. Hogenson, Gordon R. Toombs, Steven Adam, and James V. Tompkins of The Boeing Co. for **Johnson Space Center**.

Title to this invention has been waived under the provisions of the National Aeronautics and Space Act {42 U.S.C. 2457(f)}, to The Boeing Company. Inquiries concerning licenses for its commercial development should be addressed to:

The Boeing Company
PO Box 2515
2201 Seal Beach Blvd.
Seal Beach, CA 90740-1515
Phone No. (562) 797-2020

Refer to MSC-24018, volume and number of this NASA Tech Briefs *issue, and the page number.*

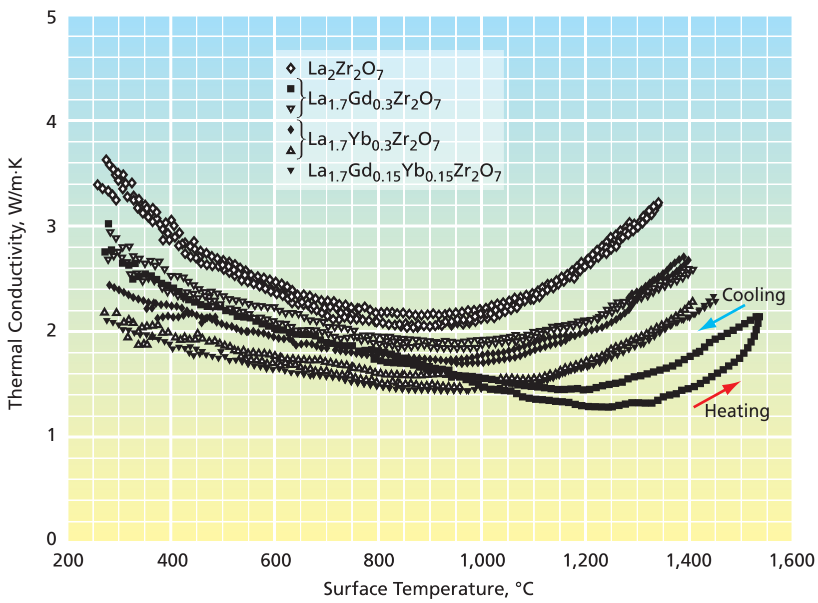
Lower-Conductivity Ceramic Materials for Thermal-Barrier Coatings

Thermal conductivities of certain pyrochlore oxides can be reduced by doping.

John H. Glenn Research Center, Cleveland, Ohio

Doped pyrochlore oxides of a type described below are under consideration as alternative materials for high-temperature thermal-barrier coatings (TBCs). In comparison with partially-yttria-stabilized zirconia (YSZ), which is the state-of-the-art TBC material now in commercial use, these doped pyrochlore oxides exhibit lower thermal conductivities, which could be exploited to obtain the following advantages:

- For a given difference in temperature between an outer coating surface and the coating/substrate interface, the coating could be thinner. Reductions in coating thicknesses could translate to reductions in weight of hot-section components of turbine engines (e.g., combustor liners, blades, and vanes) to



Measured Thermal Conductivities of hot-pressed disks of several related pyrochlore oxide compositions illustrate the benefit afforded by doping.

which TBCs are typically applied.

- For a given coating thickness, the difference in temperature between the outer coating surface and the coating/substrate interface could be greater. For turbine engines, this could translate to higher operating temperatures, with consequent increases in efficiency and reductions in polluting emissions.

TBCs are needed because the temperatures in some turbine-engine hot sections exceed the maximum temperatures that the substrate materials (superalloys, Si-based ceramics, and others) can withstand. YSZ TBCs are applied to engine components as thin layers by plasma spraying or electron-beam physical vapor deposition. During operation at higher temperatures, YSZ layers undergo sintering, which increases their thermal conductivities and thereby renders them less effective as TBCs. Moreover, the sintered YSZ TBCs are less tolerant of stress and strain and, hence, are less durable.

The materials that are sought as alternatives to YSZ are required to have and retain lower thermal conductivities and to be better able to withstand temperatures that degrade TBCs made of YSZ. The undoped versions of the doped pyrochlore oxides of the type now under consideration as alternatives to YSZ are of general composition $Ma_2Mb_2O_7$, where *Ma* denotes a 3+ cation (for example, La to Lu) and *Mb* a 4+ cation (for example, Zr, Hf, Ti). Doping has been investigated as a means of reducing thermal conductivities even further below those of YSZ coatings. In the doping approach investigated thus far, another cation is substituted for part of *Ma*, yielding a general composition of $Ma_{2-x}M_xMb_2O_7$, where x lies between 0 and 0.5 and M denotes a rare-earth or other suitable element.

In experiments, powders of various compositions were synthesized by a modified sol-gel method and calcined at appropriate temperatures to convert them into compounds of pyrochlore structure as confirmed by x-ray diffraction. These powders were hot pressed into dense disks of 1-in. (2.54-cm) diameter. The thermal conductivities of the disks were measured at various temperatures up to 1,550 °C by use of a steady-state laser heat-flux technique. The figure presents results of such measurements performed on several materials of general composition $La_{2-x}(Gd\ and/or\ Yb)_xZr_2O_7$, where $x = 0$ or 0.3. The thermal conductivities of all doped samples ($x = 0.3$) were less than those of the undoped ($x = 0$) sample [$La_2Zr_2O_7$]. The lowest conductivity — ranging from 40 to 50 percent below that of undoped sample — was exhibited by the sample co-doped with both Gd and Yb.

This work was done by Narottam P. Bansal of **Glenn Research Center** *and Dongming Zhu of the U. S. Army Research Laboratory. 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
Innovative Partnerships Office
Attn: Steve Fedor
Mail Stop 4–8
21000 Brookpark Road
Cleveland, Ohio 44135

Refer to LEW-17469-1.

Electronics/Computers

An Alternative for Emergency Preemption of Traffic Lights

This system resolves potential conflicts among emergency vehicles.

NASA's Jet Propulsion Laboratory, Pasadena, California

An electronic communication-and-control system has been developed as a prototype of advanced means of automatically modifying the switching of traffic lights to give priority to emergency vehicles. This system could be used alternatively or in addition to other emergency traffic-light-preemption systems, including a variety of systems now in use as well as two proposed systems described in "Systems Would Preempt Traffic Lights for Emergency Vehicles" (NPO-30573), *NASA Tech Briefs*, Vol. 28, No. 10 (October 2004), page 36. Unlike those prior systems that depend on detection of sounds and/or lights emitted by emergency vehicles, this system is not subject to severe range limitations. This system can be retrofitted into any pre-existing traffic-light-control system, without need to modify that system other than to make a minimal number of wire connections between the two systems.

This system comprises several subsystems, including a transponder and interface circuitry on each emergency vehicle, a monitoring and control unit at each intersection equipped with traffic lights, and a wide-area two-way radio communication network that connects the emergency vehicles and intersection units. Computers in the various intersections and vehicle units run special-purpose software that implements the traffic-light-preemption scheme. The operations of the intersection and vehicle units are synchronized by use of Global Positioning System (GPS) timing signals. The transponder in each vehicle estimates its own position and velocity by use of GPS signals, deductive ("dead") reckoning, data from the onboard diagnostic (OBD) computer of the vehicle, and/or triangulation of beacon signals.

When the operator of an emergency vehicle turns on its flashing lights and sirens in response to a request for an emergency response, the transponder unit goes into action, reading the OBD data to determine speed and acceleration, and reading and gathering further navigational data as described above. The position, velocity, and acceleration data are combined with vehicle-identification data in a prescribed format, and the resulting set of data is transmitted to the intersections within communication range of the transponder.

In each intersection unit that receives such a data signal, a processor estimates the time of arrival of the vehicle, compares it with the estimated times of arrival of other emergency vehicles approaching the intersection, and determines which vehicle will arrive first. The intersection unit notifies the transponders of all emergency vehicles of a potential conflict and states, as part of the notice, which vehicle has the right of way. At the same time, the processor collects information on the current operation of the traffic lights at the intersection and calculates when pedestrians should be alerted not to cross and when preemption of the traffic lights should start. When preemption starts, the traffic lights are augmented by textual displays of a message that emergency vehicles are approaching and graphical displays indicating the direction(s) of approach. Once the emergency vehicles have passed through the intersection, normal operation of the traffic lights is resumed.

This work was done by Conrad Foster and Aaron Bachelder 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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JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-30604, volume and number of this NASA Tech Briefs *issue, and the page number.*

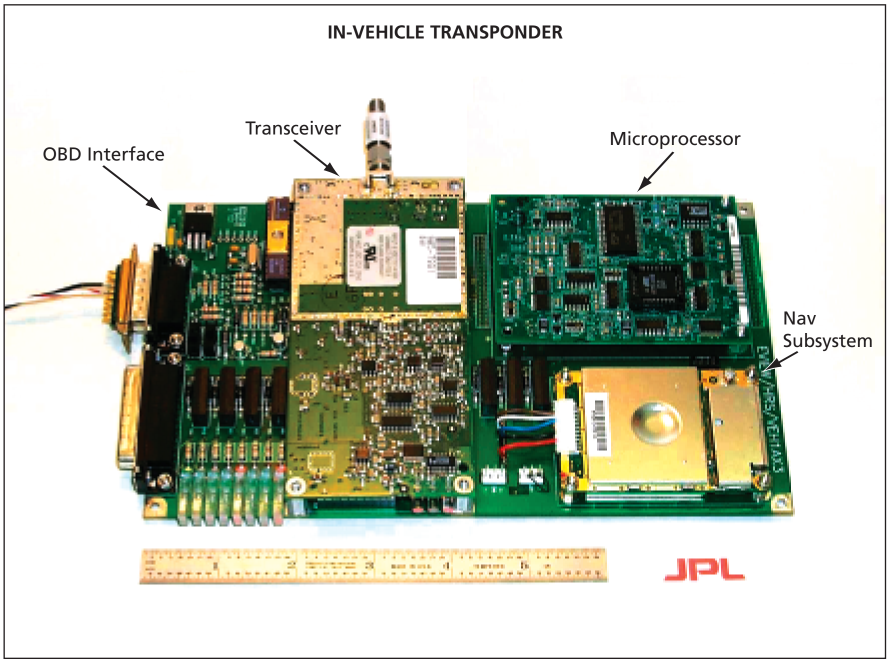
Vehicle Transponder for Preemption of Traffic Lights

This unit provides timely information on statuses of vehicles and intersections.

NASA's Jet Propulsion Laboratory, Pasadena, California

The purpose of this article is to describe, in more detail, the transponder installed in each vehicle that participates in the emergency traffic-light-preemption system described in the immediately preceding article. The transponder (see figure) is a fully autonomous data-collection, data-processing, information-display, and communication subsystem that performs robustly in preemption of traffic lights and monitoring of the statuses of street intersections.

This transponder monitors the condition of the emergency vehicle in which it is installed and determines when the vehicle has been placed in an emergency-response condition with its siren and/or warning lights activated. Upon detection of such a condition, the transponder collects real-time velocity and acceleration data from the onboard diagnostic (OBD) computer of the vehicle. For this purpose, the transponder contains an OBD interface circuit, including a microprocessor that determines the manufacturer and model of the vehicle and then sends the appropriate commands to the OBD computer requesting the speed and acceleration data. At the same time, data from an onboard navigation



An **Emergency-Vehicle Transponder** contains electronic circuits designed by NASA's Jet Propulsion Laboratory. The transponder is packaged such that it can be easily mounted in the vehicle in less than one hour.

system are collected to determine the location and the heading of the vehicle. Then acceleration, speed, position, and heading data are processed and combined with a vehicle-identification number and the resulting set of data is transmitted to monitoring and control units located at all intersections within communication range.

When the unit at an intersection determines that this vehicle is approaching and has priority to preempt the intersection, it transmits a signal declaring the priority and the preemption to all participating vehicles (including this one) in the vicinity. If the unit at the intersection has determined that other participating vehicles are also approaching the intersection, then this unit also transmits, to the vehicle that has priority, a message that the other vehicles are approaching the same intersection. The texts of these messages, plus graphical symbols that show the directions and numbers of the approaching vehicles, are presented on the display panel of a computer that is part of the transponder.

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

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Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-30607, volume and number of this NASA Tech Briefs *issue, and the page number.*

Automated Announcements of Approaching Emergency Vehicles

Pedestrians would be given advance warning.

NASA's Jet Propulsion Laboratory, Pasadena, California

Street intersections that are equipped with traffic lights would also be equipped with means for generating audible announcements of approaching emergency vehicles, according to a proposal. The means to generate the announcements would be implemented in the intersection-based subsystems of emergency traffic-light-preemption systems like those described in the two immediately preceding articles and in "Systems Would Preempt Traffic Lights for Emergency Vehicles" (NPO-30573), *NASA Tech Briefs*, Vol. 28, No. 10 (October 2004), page 36.

Preempting traffic lights is not, by itself, sufficient to warn pedestrians at affected intersections that emergency vehicles are approaching. Automated visual displays that warn of approaching emergency vehicles can be helpful as a supplement to preemption of traffic lights, but experience teaches that for a variety of reasons, pedestrians often do not see such displays. Moreover, in noisy and crowded urban settings, the lights and sirens on emergency vehicles are often not noticed until a few seconds before the vehicles arrive.

According to the proposal, the traffic-light preemption subsystem at each intersection would generate an audible announcement — for example, "emergency vehicle approaching, please clear intersection" — whenever a preemption was triggered. The subsystem would estimate the time of arrival of an approaching emergency vehicle by use of vehicle identity, position, and time data from one or more sources that could include units connected to traffic loops and/or transponders connected to diagnostic and navigation systems in participating emergency vehicles. The intersection-based subsystem would then start the announcement far enough in advance to enable pedestrians to leave the roadway before any emergency vehicles arrive.

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

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JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

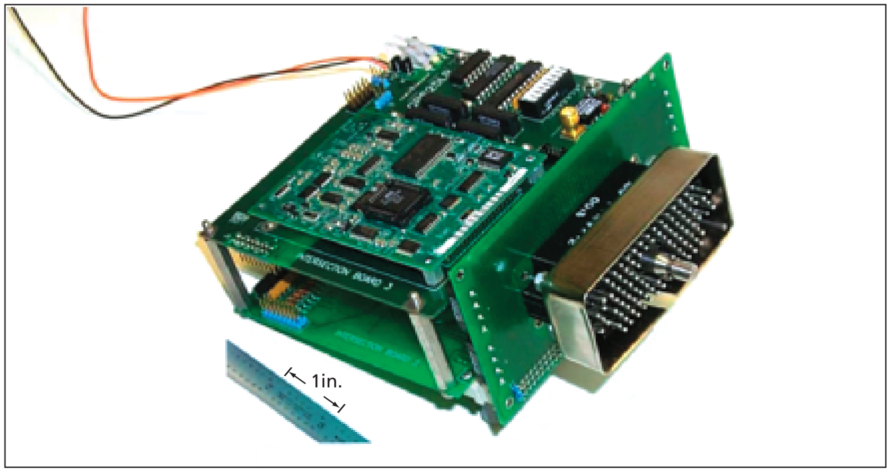
Refer to NPO-30623, volume and number of this NASA Tech Briefs *issue, and the page number.*

Intersection Monitor for Traffic-Light-Preemption System

This unit provides real-time phase data essential for effective preemption.

NASA's Jet Propulsion Laboratory, Pasadena, California

The figure shows an intersection monitor that is a key subsystem of an emergency traffic-light-preemption system that could be any of the systems described in the three immediately preceding articles and in "Systems Would Preempt Traffic Lights for Emergency Vehicles" (NPO-30573), *NASA Tech Briefs*, Vol. 28, No. 10 (October 2004), page 36. This unit is so named because it is installed at an intersection, where it monitors the phases (in the sense of timing) of the traffic lights. The mode of operation of this monitor is independent of the type of traffic-light-controller hardware or software in use at the intersection. Moreover, the design of the monitor is such that (1) the monitor does not, by itself, affect the operation of the traffic-light controller and (2) in the event of a failure of the monitor, the traffic-light controller continues to function normally (albeit without preemption).



The **Intersection Monitor**, shown here with its covers off, provides real-time data on the phases of traffic lights at an intersection, without interfering with the traffic-light control circuitry.

The monitor is installed in series with the traffic-light controller at an intersection. The control signals of interest are monitored by use of high-impedance taps on affected control lines. These taps are fully isolated and further protected by high-voltage diodes that prevent any voltages or short circuits that arise within the monitor from affecting the controller. The signals from the taps are processed digitally and cleaned up by use of high-speed logic gates, and the resulting data are passed on to other parts of the traffic-light-preemption intersection subsystem. The data are compared continuously with data from vehicles and used to calculate timing for reliable preemption of the traffic lights. The pedestrian crossing at the intersection is also monitored, and pedestrians are warned not to cross during preemption.

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

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JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-30612, volume and number of this NASA Tech Briefs *issue, and the page number.*

Full-Duplex Digital Communication on a Single Laser Beam

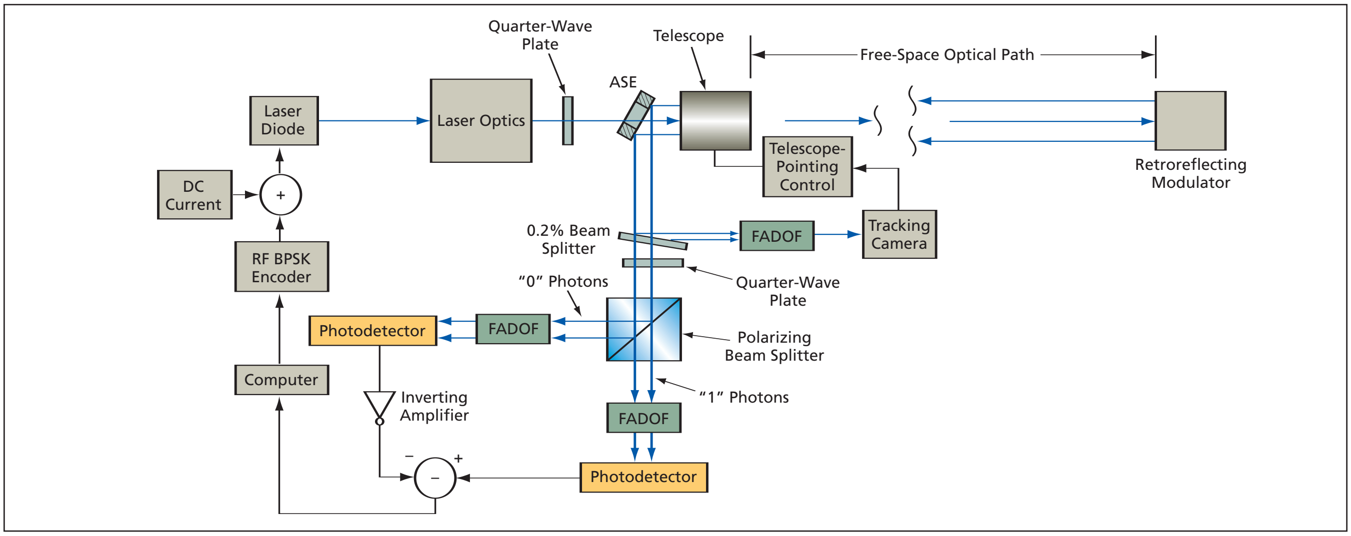
The laser beam would be transmitted with one modulation and retroreflected with another modulation.

Goddard Space Flight Center, Greenbelt, Maryland

A proposed free-space optical communication system would operate in a full-duplex mode, using a single constant-power laser beam for transmission and reception of binary signals at both ends of the free-space optical path. The system was conceived for two-way data communication between a ground station and a spacecraft in a low orbit around the Earth. It has been estimated that in this application, a data rate of 10 kb/s could be achieved at a ground-station-to-spacecraft distance of 320 km, using a laser power of only 100 mW. The basic system concept is also applicable to terrestrial free-space optical communications.

The system (see figure) would include a diode laser at one end of the link (originally, the ground station) and a liquid-crystal-based retroreflecting modulator at the other end of the link (originally, the spacecraft). At the laser end, the beam to be transmitted would be made to pass through a quarter-wave plate, which would convert its linear polarization to right circular polarization. For transmission of data from the laser end to the retroreflector end, the laser beam would be modulated with subcarrier phase-shift keying (SC-PSK). The transmitted beam would then pass through an aperture-sharing element (ASE) — basically, a mirror with a hole in it, used to separate the paths of the transmitted and received light beams. The transmitted beam would continue outward through a telescope (which, in the original application, would be equipped with a spacecraft-tracking system) that would launch the transmitted beam along the free-space optical path to the retroreflector end.

At the retroreflector end, a portion of the received laser beam would be sent to a demodulator for detection of the SC-PSK signal. For transmitting data to the laser end, the retroreflected portion of the received laser beam would be modulated with circular-polarization keying (CPK), in which left circular polarization signifies a binary level ("1" in this case) and right circu-



The **Laser at One End** of the free-space optical path would provide all of the beam power needed for transmission of data signals in both directions along the path.

lar polarization signifies the other binary level ("0" in this case). Hence, to transmit "0," the retroreflecting modulator would leave the right circular polarization of the retroreflected beam unchanged; to transmit "1," the retroreflecting modulator would flip the polarization of the reflected beam to left circular. Full-duplex operation would be possible because the CPK and the SC-PSK would be transparent to each other.

At the laser end, the reflected, CPK-modulated beam would return through the telescope and would then be reflected by the ASE into a receiver subsystem. A beam splitter would divert 0.2 percent of the beam power to a camera in the tracking system. The remainder of the beam would pass through the beam splitter to a quarter-wave plate, which would convert the circular polarization to two orthogonal linear polarizations. A polarizing beam splitter would then split the light in these two polarizations so that photons corresponding to "0" would go to one photodetector and photons corresponding to "1" would go to another photodetector.

It should be emphasized that this arrangement would yield a nonzero photodetector output of nominally the same magnitude for either "0" or "1." This is fundamentally different from on-off keying (OOK), in which "0" or "1" is represented by the absence or presence, respectively, of a signal. Taking advantage of this, prior to final digitization of the return signal at "0" or "1," the output of the "0" photodetector could be inverted, then subtracted from the output of the "1" photodetector to obtain twice the signal-to-noise ratio achievable in OOK.

The receiver subsystem would include Faraday-anomalous-dispersion optical filters (FADOFs), which would reject background light to such a high degree that the system could operate over a long path during daytime. The FADOFs would essentially prevent skylight from reaching the photodetectors while allowing about 80 percent of the signal photons to pass through. Without the FADOFs, it would be necessary to increase the laser power by a factor of 10 for daytime operation.

This work was done by D. A. Hazzard, J. A. MacCannell, G. Lee, E. R. Selves, D. Moore, J. A. Payne, C. D. Garrett, N. Dahlstrom, and T. M. Shay of New Mexico State University for **Goddard Space Flight 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:

New Mexico State University Las Cruces
P.O. Box 30001
Las Cruces, NM 88003

Refer to GSC-14759-1, volume and number of this NASA Tech Briefs *issue, and the page number.*

Stabilizing Microwave Frequency of a Photonic Oscillator

Microwave frequency is stabilized by stabilizing optical frequency to an atomic transition.

NASA's Jet Propulsion Laboratory, Pasadena, California

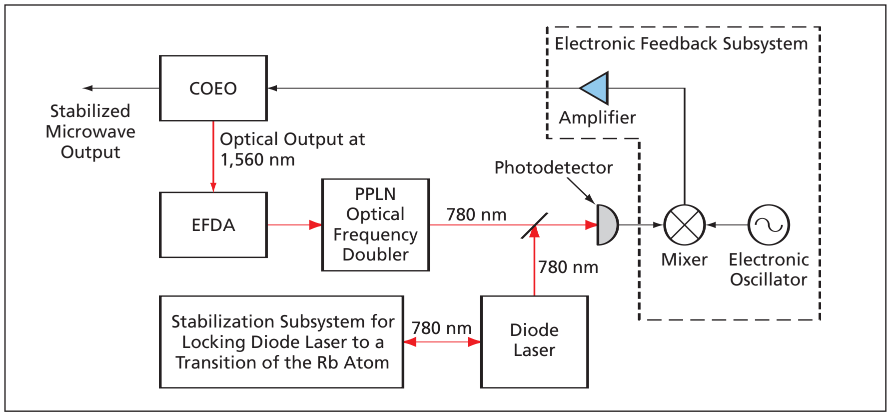
A scheme for stabilizing the frequency of a microwave signal is proposed that exploits the operational characteristics of a coupled optoelectronic oscillator (COEO) and related optoelectronic equipment. An essential element in the scheme is a fiber mode-locked laser (MLL), the optical frequency of which is locked to an atomic transition. In this scheme, the optical frequency stability of the mode-locked laser is transferred to that of the microwave in the same device. Relative to prior schemes for using wideband optical frequency comb to stabilize microwave signals, this scheme is simpler and lends itself more readily to implementation in relatively compact, rugged equipment. The anticipated development of small, low-power, lightweight, highly stable microwave oscillators based on this scheme would afford great benefits in communication, navigation, metrology, and fundamental sciences.

COEOs of various designs, at various stages of development, in some cases called by different names, have been described in a number of prior *NASA Tech Briefs* articles. A COEO is an optoelectronic apparatus that generates both short (picosecond) optical pulses and a steady microwave signal having an ultra-high degree of spectral purity. The term "coupled optoelectronic" in the full name of such an apparatus signifies that its optical and electronic oscillations are coupled to each other in a single device.

The present frequency-stabilization scheme is best described indirectly by describing the laboratory apparatus used to demonstrate it. The apparatus (see figure) includes a COEO that generates a comblike optical spectrum, the various frequency components of which interfere, producing short optical pulses. This spectrum is centered at a nominal wavelength of 1,560 nm. The spectrum separation of this comb is about 10 GHz, as determined primarily by the length of an optical loop and the bandpass filter in the microwave feedback loop. The optical loop serves as microwave resonator having a very high value of the resonance quality factor (Q). The optical frequency of MLL is then stabilized by locking it to an atomic transition as described below.

The COEO contains a tunable 1-nm band-pass optical filter and a piezoelectric-transducer (PZT) drum over which a stretch of fiber is wound. The 1-nm-wide pass band of the filter provides coarse tuning to overlap the frequency comb with the atomic transition frequency. Controlled stretching of the fiber by means of the PZT drum can be used in conjunction with temperature control for locking the laser frequency. To reference to an atomic resonance at 780 nm in this demonstration setup, the optical output of the COEO at 1,560 nm is fed through an erbium-doped-fiber amplifier (EDFA) to a frequency doubler in the form of a periodically poled lithium niobate (PPLN) crystal. The frequency-doubled output is combined with the output of a separate frequency-stabilized diode laser at a photodetector. As described thus far, the two 780-nm laser subsystems are nominally independent of each other and can, therefore, operate at different frequencies. Hence, at the photodetector, the two laser beams interfere, so that the output of the photodetector includes a beat note (a component at the difference between the two laser frequencies).

The beat note is used to stabilize the relative frequency between the two optical signals through a simple electronic feedback subsystem that adjusts the voltage applied to the PZT to lock the optical frequency of the COEO to that of the diode laser. The diode laser is frequency stabilized to the atomic absorption of Rb vapor through frequency modulation (FM) saturation spectroscopy. The fractional frequency stability of it has been shown to be 10^{-12} at 1 second. After further optimization of design to minimize destabilizing effects, it may be possible to attain a long-term stability at 10^{-13}. Such optical frequency stability can be transferred to the microwave in the COEO device where the optical and microwave oscillators are coupled, and hence producing a highly stable microwave signal.



The **COEO Generates a Comblike Optical Spectrum** that is used to generate a microwave signal. The frequency stability of a diode laser signal locked to the frequency of an atomic transition is transferred to the microwave signal.

This work was done by Lute Maleki, Nan Yu, and Meirong Tu of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-43026

Microwave Oscillators Based on Nonlinear WGM Resonators

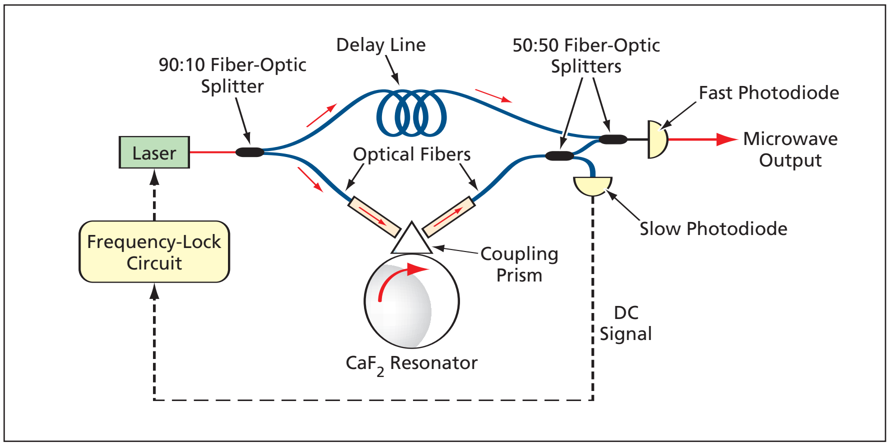
Optical signals are phase-modulated with spectrally pure microwave signals.

NASA's Jet Propulsion Laboratory, Pasadena, California

Optical oscillators that exploit resonantly enhanced four-wave mixing in nonlinear whispering-gallery-mode (WGM) resonators are under investigation for potential utility as low-power, ultra-miniature sources of stable, spectrally pure microwave signals. There are numerous potential uses for such oscillators in radar systems, communication systems, and scientific instrumentation.

The resonator in an oscillator of this type is made of a crystalline material that exhibits cubic Kerr nonlinearity, which supports the four-photon parametric process also known as four-wave mixing. The oscillator can be characterized as all-optical in the sense that the entire process of generation of the microwave signal takes place within the WGM resonator. The resonantly enhanced four-wave mixing yields coherent, phase-modulated optical signals at frequencies governed by the resonator structure. The frequency of the phase-modulation signal, which is in the microwave range, equals the difference between the frequencies of the optical signals; hence, this frequency is also governed by the resonator structure. Hence, further, the microwave signal is stable and can be used as a reference signal.

The figure schematically depicts the apparatus used in a proof-of-principle experiment. Linearly polarized pump light was generated by an yttrium aluminum garnet laser at a wavelength of 1.32 µm. By use of a 90:10 fiber-optic splitter and optical fibers, some of the laser light was sent into a delay line and some was transmitted to one face of glass coupling prism, that, in turn, coupled the laser light into a crystalline CaF_2 WGM disk resonator that had a resonance quality factor (Q) of 6×10^9. The output light of the resonator was collected via another face of the coupling prism and a single-mode optical fiber, which transmitted the light to a 50:50 fiber-optic splitter. One output of this splitter was sent to a slow photodiode to obtain a DC signal for locking the laser to a particular resonator mode. The other output of this splitter was combined with the delayed laser signal in another 50:50 fiber-optic splitter used as a combiner. The output



This **Laboratory Setup** was used to demonstrate the basic principle of generating a microwave signal in a low-threshold hyperparametric process.

of the combiner was fed to a fast photodiode that demodulated light and generated microwave signal.

In this optical configuration, the resonator was incorporated into one arm of a Mach-Zehnder interferometer, which was necessary for the following reasons: It was found that when the output of the resonator was sent directly to a fast photodiode, the output of the photodiode did not include a measurable microwave signal. However, when the resonator was placed in an arm of the interferometer and the delay in the other arm was set at the correct value, the microwave signal appeared. Such behavior is distinctly characteristic of phase-modulated light.

The phase-modulation signal had a frequency of about 8 GHz, corresponding to the free spectral range of the resonator. The spectral width of this microwave signal was less than 200 Hz. The threshold pump power for generating the microwave signal was about 1 mW. It would be possible to reduce the threshold power by several orders of magnitude if resonators could be made from crystalline materials in dimensions comparable to those of microresonators heretofore made from fused silica.

This work was done by Lute Maleki, Andrey Matsko, Anatoliy Savchenkov, and Dmitry Strekalov 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:

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-41074, volume and number of this NASA Tech Briefs *issue, and the page number.*

Pointing Reference Scheme for Free-Space Optical Communications Systems

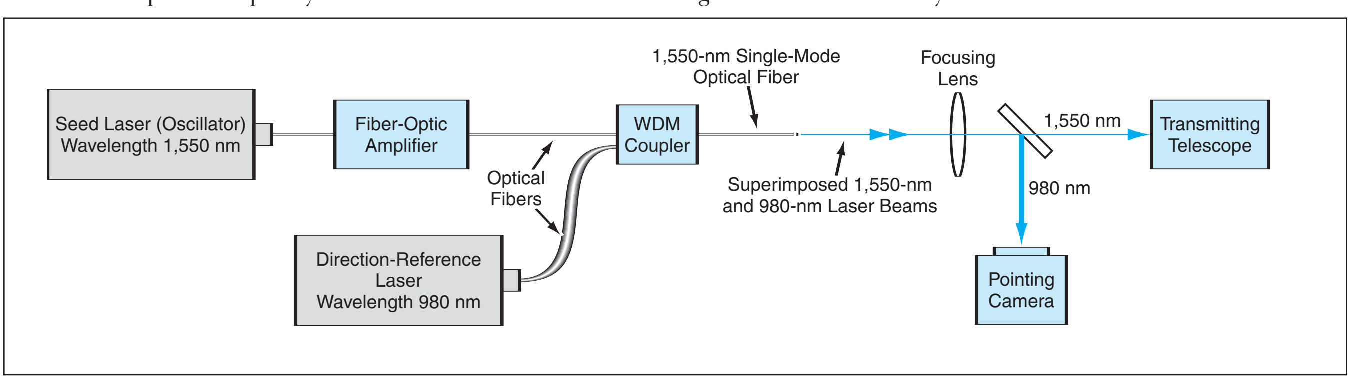
A technique is proposed for referencing infrared transmit lasers with silicon detectors.

NASA's Jet Propulsion Laboratory, Pasadena, California

A scheme is proposed for referencing the propagation direction of the transmit laser signal in pointing a free-space optical communications terminal. This recently developed scheme enables the use of low-cost, commercial silicon-based sensors for tracking the direction of the transmit laser, regardless of the transmit wavelength. Compared with previous methods, the scheme offers some advantages of less mechanical and optical complexity and avoids expensive and exotic sensor technologies.

In free-space optical communications, the transmit beam must be accurately pointed toward the receiver in order to maintain the communication link. The current approaches to achieve this function call for part of the transmit beam to be split off and projected onto an optical sensor used to infer the pointed direction. This requires that the optical sensor be sensitive to the wavelength of the transmit laser. If a different transmit wavelength is desired, for example to obtain a source capable of higher data rates, this can become quite impractical because of the unavailability or inefficiency of sensors at these wavelengths. The innovation proposed here decouples this requirement by allowing any transmit wavelength to be used with any sensor.

We have applied this idea to a particular system that transmits at the standard



An **Example Implementation** is shown of the much simpler pointing reference scheme.

telecommunication wavelength of 1,550 nm and uses a silicon-based sensor, sensitive from 0.5 to 1.0 micrometers, to determine the pointing direction. The scheme shown in the figure involves integrating a low-power 980-nm reference or boresight laser beam coupled to the 1,550-nm transmit beam via a wavelength-division-multiplexed fiber coupler. Both of these signals propagate through the optical fiber where they achieve an extremely high level of co-alignment before they are launched into the telescope. The telescope uses a dichroic beam splitter to reflect the 980-nm beam onto the silicon image sensor (a quad detector, charge-coupled device, or active-pixel-sensor array) while the 1,550-nm signal beam is transmitted through the optical assembly toward the remotely located receiver. Since the 980-nm reference signal originates from the same single-mode fiber-coupled source as the transmit signal, its position on the sensor is used to accurately determine the propagation direction of the transmit signal.

The optics are considerably simpler in the proposed scheme due to the use of a single aperture for transmitting and receiving. Moreover, the issue of mechanical misalignment does not arise because the reference signal and transmitted laser beams are inherently co-aligned. The beam quality of the 980-nm reference signal used for tracking is required to be circularly symmetric and stable at the tracking-plane sensor array in order to minimize error in the centroiding algorithm of the pointing system. However, since the transmit signal is delivered through a fiber that supports a single mode at 1,550 nm, propagation of higher order 980-nm modes is possible. Preliminary analysis shows that the overall mode profile is dominated by the fundamental mode, giving a near symmetric profile. The instability of the mode was also measured and found to be negligible in comparison to the other error contributions in the centroid position on the sensor array.

This work was done by Malcolm Wright, Gerardo Ortiz, and Muthu Jeganathan 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:

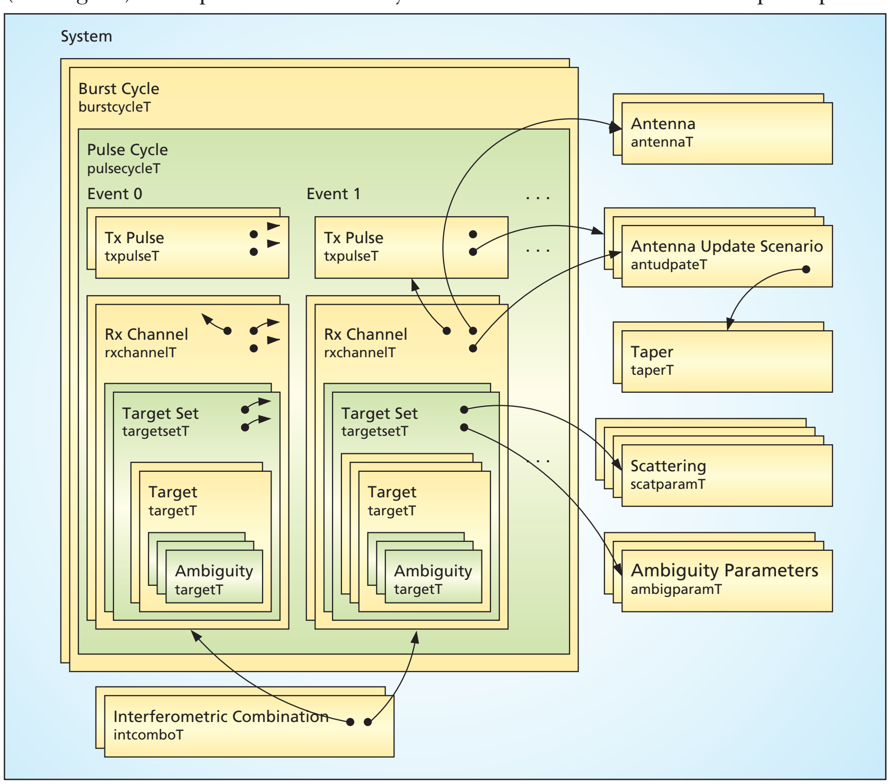
Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-30606, volume and number of this NASA Tech Briefs *issue, and the page number.*

High-Level Performance Modeling of SAR Systems

NASA's Jet Propulsion Laboratory, Pasadena, California

SAUSAGE (Still Another Utility for SAR Analysis that's General and Extensible) is a computer program for modeling (see figure) the performance of synthetic-aperture radar (SAR) or interferometric synthetic-aperture radar (InSAR or IFSAR) systems. The user is assumed to be familiar with the basic principles of SAR imaging and interferometry. Given design parameters (e.g., altitude, power, and bandwidth) that characterize a radar system, the software predicts various performance metrics (e.g., signal-to-noise ratio and resolution). SAUSAGE is intended to be a general software tool for quick, high-level evaluation of radar designs; it is not meant to capture all the subtleties, nuances, and particulars of specific systems. SAUSAGE was written to facilitate the exploration of engineering tradeoffs within the multidimensional space of design parameters. Typically, this space is examined through an iterative process of adjusting the values of the design parameters and examining the effects of the adjustments on the overall performance of the system at each iteration. The software is designed to be modular and extensible to enable consideration of a variety of operating modes and antenna beam patterns, including, for example, strip-map and spotlight SAR acquisitions, polarimetry, burst modes, and squinted geometries.



Logical Block Diagram shows how a radar system is modeled by SAUSAGE. Blocks represent software objects, which describe physical aspects of the system. Arrays are indicated by stacked blocks. Arrows represent pointers to other objects.

This program was written by Curtis Chen 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-43373.

Spectral Analysis Tool 6.2 for Windows

NASA's Jet Propulsion Laboratory, Pasadena, California

Spectral Analysis Tool 6.2 is the latest version of a computer program that assists in analysis of interference between radio signals of the types most commonly used in Earth/spacecraft radio communications. [An earlier version was reported in "Software for Analyzing Earth/Spacecraft Radio Interference" (NPO-20422), *NASA Tech Briefs*, Vol. 25, No. 4 (April 2001), page 52.] SAT 6.2 calculates signal spectra, bandwidths, and interference effects for several families of modulation schemes. Several types of filters can be modeled, and the program calculates and displays signal spectra after filtering by any of the modeled filters. The program accommodates two simultaneous signals: a desired signal and an interferer. The interference-to-signal power ratio can be calculated for the filtered desired and interfering signals. Bandwidth-occupancy and link-budget calculators are included for the user's convenience. SAT 6.2 has a new software structure and provides a new user interface that is both intuitive and convenient. SAT 6.2 incorporates multi-tasking, multithreaded execution, virtual memory management, and a dynamic link library. SAT 6.2 is designed for use on 32-bit computers employing Microsoft Windows operating systems.

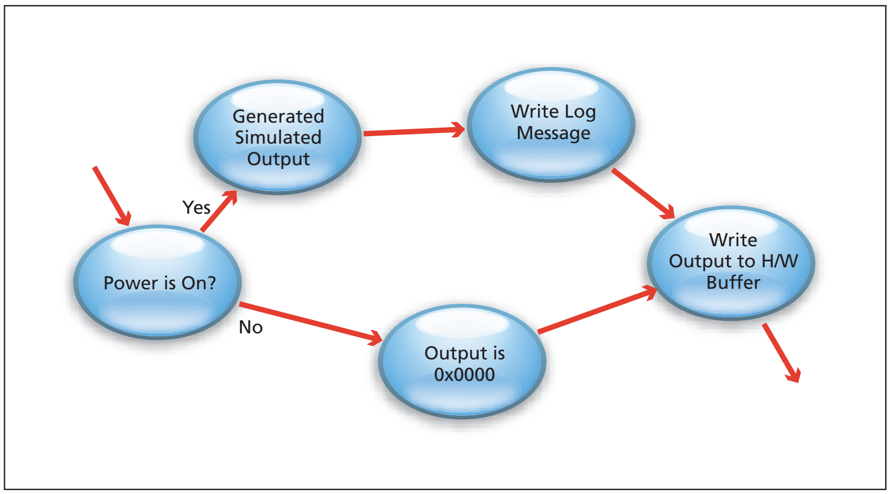
This program was written by Feiming Morgan, Miles Sue, Ted Peng, Harry Tan, and Robert Liang of Caltech and Peter Kinman of California State University, Fresno, for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-43129.

Multi-Platform Avionics Simulator

NASA's Jet Propulsion Laboratory, Pasadena, California

Multi-Platform Avionics Simulator (MPAvSim) is a software library for development of simulations of avionic hardware. MPAvSim facilitates simulation of interactions between flight software and such avionic peripheral equipment as telecommunication devices, thrusters, pyrotechnic devices, motor controllers, and scientific instruments. MPAvSim focuses on the behavior of avionics as seen by flight software, rather than on performing high-fidelity simulations of dynamics. However, MPAvSim is easily integrable with other programs that do perform such simulations. MPAvSim makes it possible to do real-time partial hardware-in-the-loop simulations. An MPAvSim simulation consists of execution chains (see figure) represented by flow graphs of models, defined here as stateless procedures that do some work. During a simulation, MPAvSim walks the execution chain, running each model in turn. Using MPAvSim, flight software can be run against a spacecraft that is all simulation, all hardware, or part hardware and part simulation. With respect to a specific piece of hardware, either the hardware itself or its simulation can be plugged in without affecting the rest of the system. Thus, flight software can be tested before hardware is available, and as items of hardware become available, they can be substituted for their simulations, with minimal disruption.



A **Simple Execution Chain** is shown for a device with a power switch.

This program was written by Micah Clark, Robert Steinke, and Elihu McMahon 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41277.

Silicon-Based Optical Modulator With Ferroelectric Layer

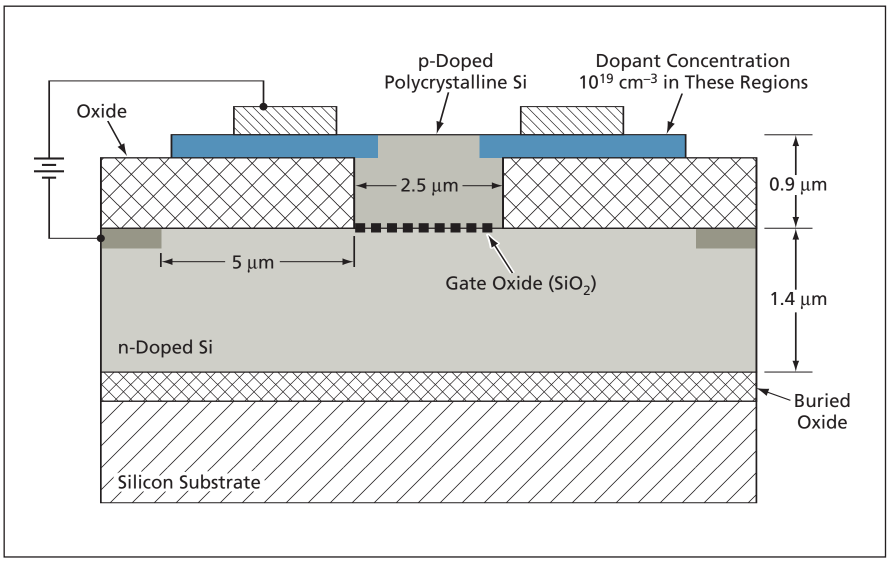
This device would remain switched even with power turned off.

NASA's Jet Propulsion Laboratory, Pasadena, California

According to a proposal, a silicon dioxide layer in a high-speed, low-power, silicon-based electro-optical modulator would be replaced by a layer of lead zirconate titanate or other ferroelectric oxide material. The purpose of this modification is to enhance the power performance and functionality of the modulator.

In its unmodified form, the particular silicon-based electro-optical modulator is of an advanced design that overcomes the speed limitation of prior silicon-based electro-optical modulators. Whereas modulation frequencies of such devices had been limited to about 20 MHz, this modulator can operate at modulation frequencies as high as 1 GHz. This modulator can be characterized as a silicon-waveguide-based metal oxide/semiconductor (MOS) capacitor phase shifter in which modulation of the index of refraction in silicon is obtained by exploiting the free-charge-carrier-plasma dispersion effect. As shown in the figure, the modulator includes an n-doped crystalline silicon slab (the silicon layer of a silicon-on-insulator wafer) and a p-doped polycrystalline silicon rib with a gate oxide layer (the aforementioned silicon dioxide layer) sandwiched between them.

Under accumulation conditions, the majority charge carriers in the silicon waveguide modify the index of refraction so that a phase shift is induced in the optical mode propagating in the waveguide. The advantage of using an MOS capacitor phase shifter is that it is possible to achieve high modulation speed because there are no slow carrier-generation or -recombination processes involved in the accumulation operation.



A **Ferroelectric Oxide Layer** would be substituted for the gate oxide layer in this silicon-based electro-optical modulator.

The main advantage of the proposed substitution of a ferroelectric oxide layer for the silicon dioxide layer would arise from the spontaneous polarization effect of the ferroelectric layer: This spontaneous polarization would maintain accumulation conditions in the absence of applied voltage. Consequently, once the device had been switched to a given optical state, it would remain in that state, even in the absence of applied voltage (in other words, even with power turned off). A secondary advantage is that because the ferroelectric layer would have an index of refraction larger than that of silicon dioxide, there could be some reduction of optical losses attributable to fabrication of the modulator.

This work was done by Douglas Sheldon 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:

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-40935, volume and number of this NASA Tech Briefs *issue, and the page number.*

Multiplexing Transducers Based on Tunnel-Diode Oscillators

Compact, low-power transducers could operate over wide temperature ranges.

NASA's Jet Propulsion Laboratory, Pasadena, California

Multiplexing and differential transducers based on tunnel-diode oscillators (TDOs) would be developed, according to a proposal, for operation at very low and/or widely varying temperatures in applications that involve requirements to minimize the power and mass of transducer electronic circuitry. It has been known since 1975 that TDOs are useful for making high-resolution (of the order of 10^{-9}) measurements at low temperatures. Since that time, TDO transducers have been found to offer the following additional advantages, which the present proposal is intended to exploit:

- TDO transducers can operate at temperatures ranging from 1 K to about 400 K. Most electronic components other than tunnel diodes do not operate over such a wide temperature range.
- TDO transducers can be made to operate at very low power — typically, <1 mW.
- Inasmuch as the response of a TDO transducer is a small change in an arbitrarily set oscillation frequency, the outputs of many TDOs operating at sufficiently different set frequencies

can be multiplexed through a single wire.

- Inasmuch as frequencies can be easily subtracted by means of mixing circuitry, one can easily use two TDOs to make differential measurements. Differential measurements are generally more precise and less susceptible to environmental variations than are absolute measurements.
- TDO transducers are tolerant to ionizing radiation.
- Ultimately, the response of a TDO transducer is measured by use of a frequency counter. Because frequency counting can be easily implemented by use of clock signals available from most microprocessors, it is not necessary to incorporate additional readout circuitry that would, if included, add to the mass and power consumption of the transducer circuitry.

In one example of many potential variations on the basic theme of the proposal, the figure schematically depicts a conceptual differential-pressure transducer containing a symmetrical pair of TDOs. The differential pressure would be exerted on an electrically conductive and grounded diaphragm, which, at zero differential pressure, would nominally be sprung to a middle position between two capacitor plates that would be parts of the two TDOs. The frequencies of the two TDOs would vary in opposite directions as variations in differential pressure bent the diaphragm away from one capacitor plate and toward the other. The outputs of the TDOs would be mixed and low-pass filtered to obtain a signal at the difference between the frequencies of the two TDOs. The difference frequency would be measured by a frequency counter and converted to differential pressure by a computer.

This work was done by Talso Chui, Konstantin Penanen, and Joseph Young of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-43079

Software

Scheduling With Automatic Resolution of Conflicts

DSN Requirement Scheduler is a computer program that automatically schedules, reschedules, and resolves conflicts for allocations of resources of NASA's Deep Space Network (DSN) on the basis of ever-changing project requirements for DSN services. As used here, "resources" signifies, primarily, DSN antennas, ancillary equipment, and times during which they are available. Examples of project-required DSN services include arraying, segmentation, very-long-baseline interferometry, and multiple spacecraft per aperture. Requirements can include periodic reservations of specific or optional resources during specific time intervals or within ranges specified in terms of starting times and durations. This program is built on the Automated Scheduling and Planning Environment (ASPEN) software system (aspects of which have been described in previous *NASA Tech Briefs* articles), with customization to reflect requirements and constraints involved in allocation of DSN resources. Unlike prior DSN-resource-scheduling programs that make single passes through the requirements and require human intervention to resolve conflicts, this program makes repeated passes in a continuing search for all possible allocations, provides a best-effort solution at any time, and presents alternative solutions among which users can choose.

This program was written by Bradley Clement and Steve Schaffer 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41313.

Symbolic Constraint Maintenance Grid

Version 3.1 of Symbolic Constraint Maintenance Grid (SCMG) is a software system that provides a general conceptual framework for utilizing pre-existing programming techniques to perform symbolic transformations of data. SCMG also provides a language (and an associated communication method and protocol) for representing constraints on the original non-symbolic data. SCMG provides a facility for exchanging information between numeric and symbolic components without knowing the details of the components themselves. In essence, it integrates symbolic software tools (for diagnosis, prognosis, and planning) with non-artificial-intelligence software. SCMG executes a process of symbolic summarization and monitoring of continuous time series data that are being abstractly represented as symbolic templates of information exchange. This summarization process enables such symbolic-reasoning computing systems as artificial-intelligence planning systems to evaluate the significance and effects of channels of data more efficiently than would otherwise be possible. As a result of the increased efficiency in representation, reasoning software can monitor more channels and is thus able to perform monitoring and control functions more effectively.

This work was done by Mark James 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42001.

Discerning Trends in Performance Across Multiple Events

Mass Data is a computer program that enables rapid, easy discernment of trends in performance data across multiple flights and ground tests. The program can perform Fourier analysis and other functions for the purposes of frequency analysis and trending of all variables. These functions facilitate identification of past use of diagnosed systems and of anomalies in such systems, and enable rapid assessment of related current problems. Many variables, for computation of which it is usually necessary to perform extensive manual manipulation of raw downlist data, are automatically computed and made available to all users, regularly eliminating the need for what would otherwise be an extensive amount of engineering analysis. Data from flight, ground test, and simulation are preprocessed and stored in one central location for instantaneous access and comparison for diagnostic and trending purposes. Rules are created so that an event log is created for every flight, making it easy to locate information on similar maneuvers across many flights. The same rules can be created for test sets and simulations, and are searchable, so that information on like events is easily accessible.

This program was written by Simon Slater, Mike Hiltz, and Craig Rice of MacDonald Dettwiler Space Robotics for **Johnson Space Center**. *For further information, contact the Johnson Technology Transfer Office at (281) 483-3809.*
MSC-23824

Magnetic Field Solver

The Magnetic Field Solver computer program calculates the magnetic field generated by a group of collinear, cylindrical axisymmetric electromagnet coils. Given the current flowing in, and the number of turns, axial position, and axial and radial dimensions of each coil, the program calculates matrix coefficients for a finite-difference system of equations that approximates a two-dimensional partial differential equation for the magnetic potential contributed by the coil. The program iteratively solves these finite-difference equations by use of the modified incomplete Cholesky preconditioned-conjugate-gradient method. The total magnetic potential as a function of axial (z) and radial (r) position is then calculated as a sum of the magnetic potentials of the individual coils, using a high-accuracy interpolation scheme. Then the r and z components of the magnetic field as functions of r and z are calculated from the total magnetic potential by use of a high-accuracy finite-difference scheme. Notably, for the finite-difference calculations, the program generates nonuniform two-dimensional computational meshes from nonuniform one-dimensional meshes. Each mesh is generated in such a way as to minimize the numerical error for a benchmark one-dimensional magnetostatic problem.

This program was written by Andrew V. Ilin of Muniz Engineering, Inc. for **Johnson Space Center**. *For further information, contact the Johnson Technology Transfer Office at (281) 483-3809.*
MSC-23618

Computing for Aiming a Spaceborne Bistatic-Radar Transmitter

BISTAT is a computer program for use in aiming a spaceborne bistatic-radar transmitting antenna at a remote planet that has an atmosphere, such that after refraction by the atmosphere and reflection from the surface of the planet, the radar signal travels toward a receiver on Earth. BISTAT includes an algorithm that neglects atmospheric refraction and calculates a specular-reflection point for a spacecraft at a given location. The specular-reflection point is then used as an initial guess for a modified limb-track algorithm that takes atmospheric refraction into account. The output of BISTAT for all spacecraft positions of interest constitutes a pointing profile; the output data are in the form of an inertial-vector file and a Doppler-residual file. The inertial-vector file is used to command the attitude of the spacecraft; the Doppler-residual file is used to determine a downlink frequency file for the receiver.

This program was written by Nicole Rappaport 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41518.

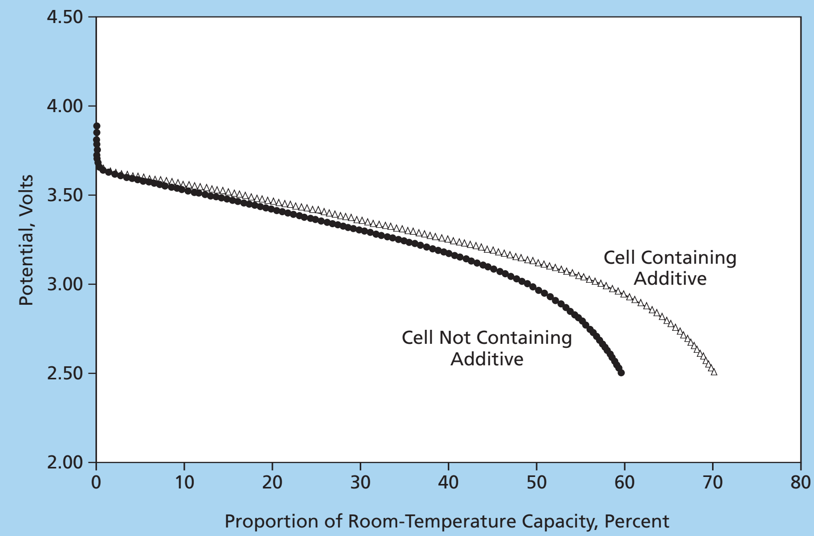
Materials

4-Vinyl-1,3-Dioxolane-2-One as an Additive for Li-Ion Cells

Low-temperature charge/discharge capacity is increased.

NASA's Jet Propulsion Laboratory, Pasadena, California

Electrolyte additive 4-vinyl-1,3-dioxolane-2-one has been found to be promising for rechargeable lithium-ion electrochemical cells. This and other additives, along with advanced electrolytes comprising solutions of $LiPF_6$ in various mixtures of carbonate solvents, have been investigated in a continuing effort to improve the performances of rechargeable lithium-ion electrochemical cells, especially at low temperatures. In contrast to work by other researchers who have investigated the use of this additive to improve the high-temperature resilience of Li-ion cells, the current work involves the incorporation of 4-vinyl-1,3-dioxolane-2-one into quaternary carbonate electrolyte mixtures, previously optimized for low-temperature applications, resulting in improved low-temperature performance.



The **Proportion of Room-Temperature Capacity** retained at –20 °C was determined, for each of two cells, from data obtained in the first five cycles of charge/discharge testing.

The benefit afforded by 4-vinyl-1,3-dioxolane-2-one can be better understood in the light of relevant information from a number of prior *NASA Tech Briefs* articles about electrolytes and additives for such cells. To recapitulate: The loss of performance with decreasing temperature is attributable largely to a decrease of ionic conductivity and the increase in viscosity of the electrolyte. What is needed to extend the lower limit of operating temperature is a stable electrolyte solution with relatively small low-temperature viscosity, a large electric permittivity, adequate coordination behavior, and appropriate ranges of solubilities of liquid and salt constituents. Whether the anode is made of graphitic or non-graphitic carbon, a film on the surface of the anode acts as a solid/electrolyte interface (SEI), the nature of which is critical to low-temperature performance. Desirably, the surface film should exert a chemically protective (passivating) effect on both the anode and the electrolyte, yet should remain conductive to lithium ions to facilitate intercalation and deintercalation of the ions into and out of the carbon during discharging and charging, respectively.

The additives investigated previously include alkyl pyrocarbonates. Those additives help to improve low-temperature performances by giving rise to the formation of SEIs having desired properties. The formation of the SEIs is believed to be facilitated by products (e.g., CO_2) of the decomposition of these additives. These decomposition products are believed to react to form Li_2CO_3-based films on the carbon electrodes.

The present additive, 4-vinyl-1,3-dioxolane-2-one, also helps to improve low-temperature performance by contributing to the formation of SEIs having desired properties, but probably in a different manner: It is believed that, as part of the decomposition process, the compound polymerizes on the surfaces of carbon electrodes.

The effectiveness of 4-vinyl-1,3-dioxolane-2-one as a performance-improving additive in several different $LiPF_6$/carbonate-solvent-mixture electrolytes was investigated in a series of charge/discharge tests of rechargeable lithium-ion electrochemical cells containing the electrolytes, at room temperature and at a temperature of –20 °C. In one pair of tests, the electrolyte comprised $LiPF_6$ dissolved at a concentration of 1.0 M in a solvent mixture comprising 1 volume part of ethylene carbonate + 1 volume part of diethyl carbonate + 1 volume part of dimethyl carbonate + 2 volume parts of ethyl methyl carbonate. In one of the tests, no additive was included; in the other test, the electrolyte included 4-vinyl-1,3-dioxolane-2-one in the proportion of 1.5 weight percent. The results of these tests showed that the additive enhanced low-temperature performance: specifically, the results showed that at –20 °C and at any given voltage, the cell containing the additive retained a greater proportion of its room-temperature capacity than did the cell that did not contain the additive (see figure).

This work was done by Marshall Smart and Ratnakumar Bugga of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-40969

Probabilistic Prediction of Lifetimes of Ceramic Parts

John H. Glenn Research Center, Cleveland, Ohio

ANSYS/CARES/PDS is a software system that combines the ANSYS Probabilistic Design System (PDS) software with a modified version of the Ceramics Analysis and Reliability Evaluation of Structures Life (CARES/Life) Version 6.0 software. [A prior version of CARES/Life was reported in "Program for Evaluation of Reliability of Ceramic Parts" (LEW-16018), *NASA Tech Briefs*, Vol. 20, No. 3 (March 1996), page 28.] CARES/Life models effects of stochastic strength, slow crack growth, and stress distribution on the overall reliability of a ceramic component. The essence of the enhancement in CARES/Life 6.0 is the capability to predict the probability of failure using results from transient finite-element analysis. ANSYS PDS models the effects of uncertainty in material properties, dimensions, and loading on the stress distribution and deformation. ANSYS/CARES/PDS accounts for the effects of probabilistic strength, probabilistic loads, probabilistic material properties, and probabilistic tolerances on the lifetime and reliability of the component. Even failure probability becomes a stochastic quantity that can be tracked as a response variable. ANSYS/CARES/PDS enables tracking of all stochastic quantities in the design space, thereby enabling more precise probabilistic prediction of lifetimes of ceramic components.

This work was done by Noel N. Nemeth and John P. Gyekenyesi of **Glenn Research Center**, *Osama M. Jadaan and Tamas Palfi of Ohio Aerospace Institute, Lynn Powers of Case Western Reserve University, Stefan Reh of ANSYS Inc., and Eric H. Baker of Connecticut Reserve Technologies, LLC. 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, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17682-1/4-1.

STRANAL-PMC Version 2.0

John H. Glenn Research Center, Cleveland, Ohio

Version 2.0 of the Strain Rate Dependent Analysis of Polymer Matrix Composites (STRANAL-PMC) software has been released. A prior version was reported in "Analyzing Loads and Strains in Polymer-Matrix Composites" (LEW-17227), *NASA Tech Briefs*, Vol. 26, No. 11 (November 2002), page 36. To recapitulate: Modified versions of constitutive equations of viscoplasticity of metals are used to represent deformation of a polymeric matrix. The equations are applied in a micromechanical approach, proceeding upward from slices of unit cells, through the ply level, to the laminate level. The constitutive equations are integrated in time by a Runge-Kutta technique. To predict the ultimate strength of each composite ply, failure criteria are implemented within the micromechanics. The inputs to STRANAL-PMC are the laminate geometry, properties of the fiber and matrix materials, and applied stress or strain versus time. The outputs are time-dependent stresses and strains at the slice, ply, and laminate levels. The improvements in version 2.0 include more rigorous representation of hydrostatic-stress effects in the matrix, refinement and extension of ply failure models, and capabilities to analyze transverse shear stresses. Version 2.0 can be implemented as a material-model code within transient dynamic finite-element codes.

This program was written by Robert Goldberg and Kelly S. Carney of **Glenn Research Center**, *Wieslaw Binienda of the University of Akron, and Aditi Chattopadhyay of Arizona State University. 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, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17910-1.

Micromechanics and Piezo Enhancements of HyperSizer

John H. Glenn Research Center, Cleveland, Ohio

The commercial HyperSizer aerospace-composite-material-structure-sizing software has been enhanced by incorporating capabilities for representing coupled thermal, piezoelectric, and piezomagnetic effects on the levels of plies, laminates, and stiffened panels. This enhancement is based on a formulation similar to that of the pre-existing HyperSizer capability for representing thermal effects. As a result of this enhancement, the electric and/or magnetic response of a material or structure to a mechanical or thermal load, or its mechanical response to an applied electric or magnetic field can be predicted. In another major enhancement, a capability for representing micromechanical effects has been added by establishment of a linkage between HyperSizer and Glenn Research Center's Micromechanics Analysis Code With Generalized Method of Cells (MAC/GMC) computer program, which was described in several prior *NASA Tech Briefs* articles. The linkage enables HyperSizer to localize to the fiber and matrix level rather than only to the ply level, making it possible to predict local failures and to predict properties of plies from those of the component fiber and matrix materials. Advanced graphical user interfaces and database structures have been developed to support the new HyperSizer micromechanics capabilities.

These enhancements were made by Steven M. Arnold of **Glenn Research Center**, *Brett A. Bednarcyk of Ohio Aerospace Institute, and Phillip WA. Yarrington and Craig S. Collier of Collier Research Corp. 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, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17819-1.

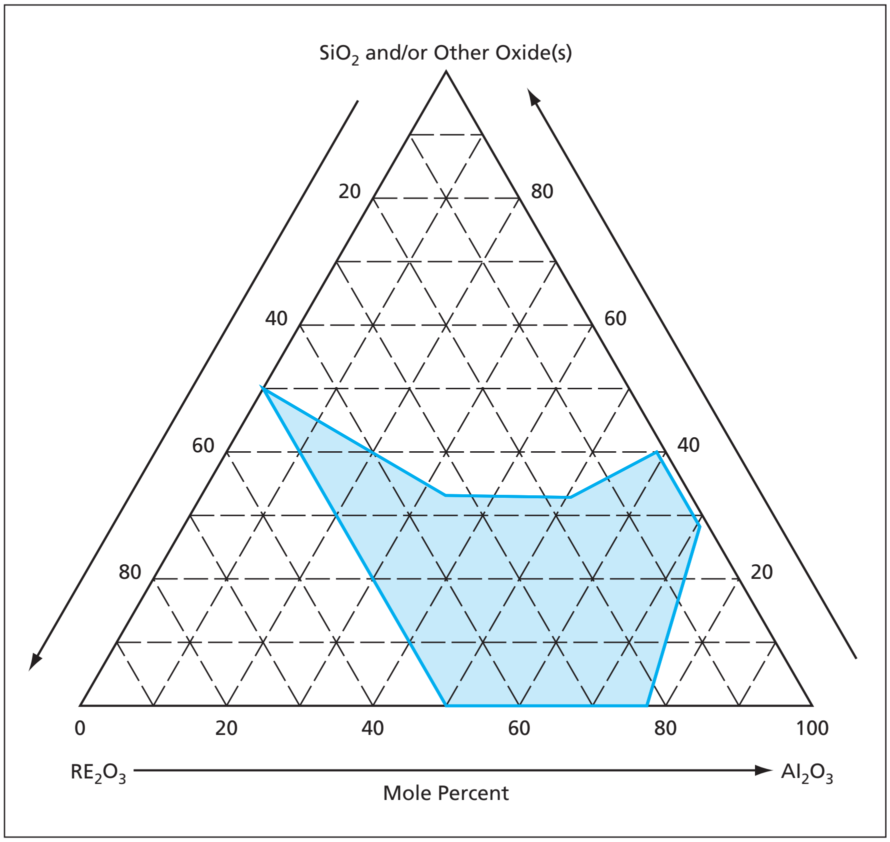
Single-Phase Rare-Earth Oxide/Aluminum Oxide Glasses

These glasses are suitable for advanced optical applications.

Marshall Space Flight Center, Alabama

Glasses that comprise rare-earth oxides and aluminum oxide plus, optionally, lesser amounts of other oxides, have been invented. The other oxide(s) can include SiO_2, B_2O_3, GeO_2, and/or any of a variety of glass-forming oxides that have been used heretofore in making a variety of common and specialty glasses. The glasses of the invention can be manufactured in bulk single-phase forms to ensure near uniformity in optical and mechanical characteristics, as needed for such devices as optical amplifiers, lasers, and optical waveguides (including optical fibers). These glasses can also be formulated to have high indices of refraction, as needed in some of such devices.

The figure presents a ternary phase diagram showing the range of proportions of the main ingredients of several glasses according to the invention. One rare-earth oxide that is included in every formulation according to the invention is La_2O_3, typically in an amount between a few mole percent and a few tens of mole percent. As in the synthesis of other glasses, the oxide ingredients are melted together, then the melt is cooled sufficiently rapidly to a temperature below the melting temperatures of the crystalline phases and below the liquidus temperature of the melt. By "sufficiently rapidly" is meant rapidly enough to ensure solidification into glass before crystallization occurs. The La_2O_3 helps to present phase separation during solidification.



The **Colored Area Within the Polygon** represents the range of compositions of single-phase glasses described in the text.

Preferably, during solidification, the melt should not be allowed to come in contact with a solid container because such contact could give rise to heterogeneous nucleation of crystalline material, preventing the formation of glass. For making a very small amount of glass, contact can be prevented by use of a containerless process in which the melt is levitated by a gas stream and heated by a CO_2 laser, then cooled by simply turning off the laser. In another containerless process better suited to production of a larger amount of glass, the glass melt is levitated on a thin gas film formed by gas flowing through a porous membrane in a furnace or an electromagnetically heated graphite susceptor.

Alternatively, a relatively large amount of glass can be formed in a conventional float glass process: First, the oxide ingredients are melted together in a crucible. Then the glass melt is cast onto a pool of a suitable molten metal (e.g., tin or gold) that remains molten (and, therefore, not crystalline) at a temperature below the temperature to which the glass melt must be rapidly cooled. Another alternative for making a relatively large amount of glass is to melt the ingredients in a crucible, then cast the melt onto a pre-cooled metal die. Some heterogeneous nucleation of crystals can occur in the glass layer in contact with the metal. However, if the rate of cooling is fast enough (in effect, if the casting is thin enough), then glass is formed before the crystals propagate through the thickness of the casting. Later, any crystals can be removed by polishing the glass surface that was in contact with the metal die.

This work was done by J. K. Richard Weber, Johan G. Abadie, April D. Hixson, and Paul C. Nordine of Containerless Research, Inc., for **Marshall Space Flight Center**. *For further information, contact the company at cri_info@containerless.com.*
MFS-32117-1

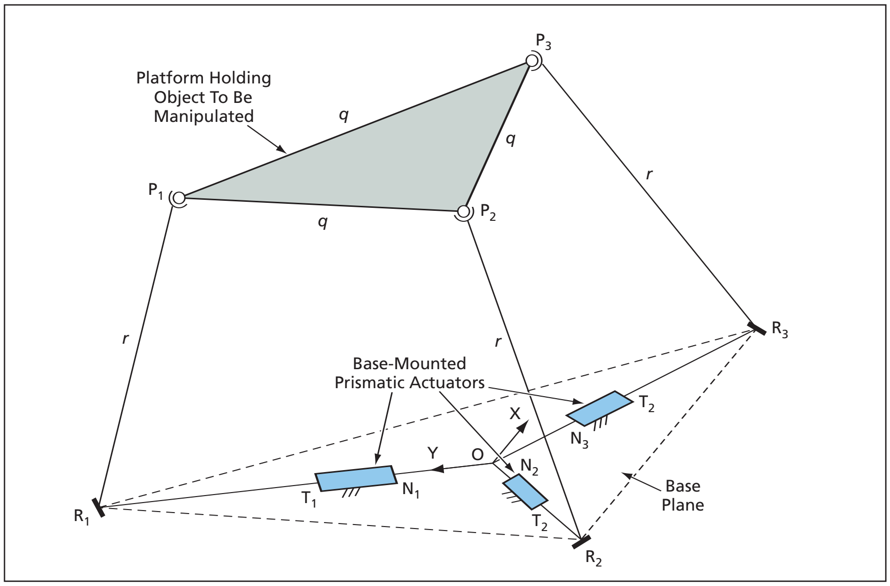
Tilt/Tip/Piston Manipulator With Base-Mounted Actuators

The geometry and kinematics of this manipulator would afford advantages for some applications.

Goddard Space Flight Center, Greenbelt, Maryland

A proposed three-degree-of-freedom (tilt/tip/piston) manipulator, suitable for aligning an optical or mechanical component, would offer several advantages over prior such manipulators:

- Unlike in some other manipulators, no actuator would support the weight of another actuator: All of the actuators would be mounted on a base. Hence, there would be less manipulated weight.
- The basic geometry of the manipulator would afford mechanical advantage: that is, actuator motions would be larger than the motions they produce in the manipulated object. Mechanical advantage inherently increases the accuracy and resolution of manipulation.
- Unlike in some other manipulators, it would not be necessary to route power and/or data lines through manipulator joints.



Lengths of Links R_1T_1, R_2T_2, and R_3T_3 are varied to adjust the piston, tilt, and tip coordinates of the platform.

The proposed manipulator (see figure) would include three prismatic actuators (T_1N_1, T_2N_2, and T_3N_3) mounted on the base and operating in the same plane. Examples of suitable prismatic actuators include lead-screw mechanisms, linear hydraulic motors, piezoelectric linear drives, inchworm-movement linear stepping motors, and linear flexure drives. The actuators would control the lengths of links R_1T_1, R_2T_2, and R_3T_3.

Three spherical joints (P_1, P_2, and P_3) would be located at the corners of an equilateral triangle of side length q on the platform holding the object to be manipulated. Three inextensible limbs (R_1P_1, R_2P_2, and R_3P_3) having length r would connect the spherical joints on the platform to revolute joints (R_1, R_2, and R_3) at the ends of the actuator-controlled links R_1T_1, R_2T_2, and R_3T_3. By varying the lengths of these links, one could control the tilt, tip, and piston coordinates of the platform. Closed-form equations for direct or forward kinematics of the manipulator (given the lengths of the variable links, find the tilt, tip, and piston coordinates) have been derived. The equations of inverse kinematics (find the variable link lengths needed to obtain the desired tilt, tip, and piston coordinates) have also been derived.

This work was done by Farhad Tahmasebi of **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*
GSC-14874-1

Measurement of Model Noise in a Hard-Wall Wind Tunnel

Spurious noise is suppressed in processing of digitized microphone outputs.

Ames Research Center, Moffett Field, California

Identification, analysis, and control of fluid-mechanically-generated sound from models of aircraft and automobiles in special low-noise, semi-anechoic wind tunnels are an important research endeavor. Such studies can also be done in aerodynamic wind tunnels that have hard walls if phased microphone arrays are used to focus on the noise-source regions and reject unwanted reflections or background noise. Although it may be difficult to simulate the total flyover or drive-by noise in a closed wind tunnel, individual noise sources can be isolated and analyzed.

An acoustic and aerodynamic study was made of a 7-percent-scale aircraft model in a NASA Ames 7-by-10-ft (about 2-by-3-m) wind tunnel for the purpose of identifying and attenuating airframe noise sources. Simulated landing, takeoff, and approach configurations were evaluated at Mach 0.26. Using a phased microphone array mounted in the ceiling over the inverted model, various

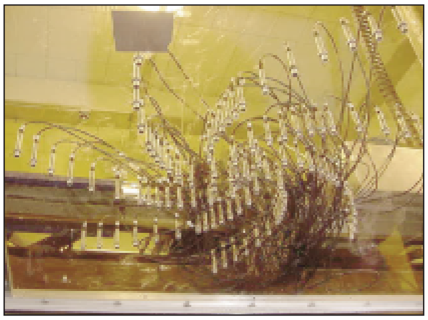


Figure 1. The **Array of Microphones** was mounted above the aircraft model in the test section of the wind tunnel. A cloth cover has been removed from under the microphones to make the model visible in this view.

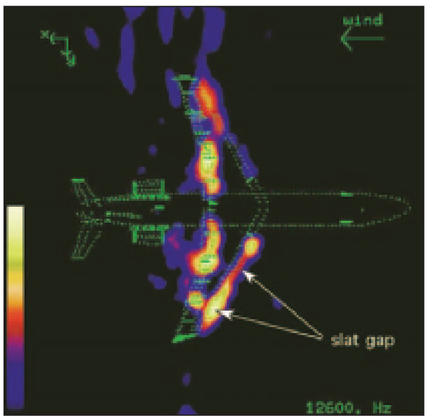


Figure 2. A **Contour Map of Wing-Slat Noise** at a frequency of 12.6 kHz was computed from measurements made by the microphone array. The color-contour range is 8 dB.

noise sources in the high-lift system, landing gear, fins, and miscellaneous other components were located and compared for sound level and frequency at one flyover location. Numerous noise-alleviation devices and modifications of the model were evaluated. Simultaneously with acoustic measurements, aerodynamic forces were recorded to document aircraft conditions and any performance changes caused by geometric modifications.

Most modern microphone-array systems function in the frequency domain in the sense that spectra of the microphone outputs are computed, then operations are performed on the matrices of microphone-signal cross-spectra. The entire acoustic field at one station in such a system is acquired quickly and interrogated during postprocessing. Beam-forming algorithms are employed to scan a plane near the model surface and locate noise sources while rejecting most background noise and spurious reflections. In the case of the system used in this study, previous studies in the wind tunnel have identified noise sources up to 19 dB below the normal background noise of the wind tunnel. Theoretical predictions of array performance are used to minimize the width and the side lobes of the beam pattern of the microphone array for a given test arrangement.

To capture flyover noise of the inverted model, a 104-element microphone array in a 622-mm-diameter cluster was installed in a 19-mm-thick poly(methyl methacrylate) plate in the ceiling of the test section of the wind tunnel above the aircraft model (see Figure 1). The microphones were of the condenser type, and their diaphragms were mounted flush in the array plate, which was recessed 12.7 mm into the ceiling and covered by a porous aromatic polyamide cloth (not shown in the figure) to minimize boundary-layer noise. This design caused the level of flow noise to be much less than that of flush-mount designs. The drawback of this design was that the cloth attenuated sound somewhat and created acoustic resonances that could grow to several dB at a frequency of 10 kHz.

A correction methodology has been developed to account for the signal interference. The first side lobe of the beam pattern was 13.4 dB down from the peak response at 8 kHz and at an angle of 23° from the normal vector: these characteristics made it possible to obtain good acoustic signals from the model when the model was located at a distance of 1.11 m from the array. Data were acquired at 12,321 scan points in a plane encompassing the model. From these data, aerodynamic noise from sources as small as 6 mm on the model surface could be identified easily.

The microphone signals were digitized at a rate of 153,600 samples per second on 104 channels simultaneously by use of analog-to-digital converter circuits and a computer. The resulting maximum acoustic frequency was 60 kHz with a bandwidth of 300 Hz. The data for frequencies <2 kHz were found to be of marginal utility because the microphone beam pattern at those frequencies was too wide. The data for frequencies >32 kHz were found to be of marginal utility because at those frequencies, the sources were too weak and the side lobes too strong. The frequency limits of 2 and 32 kHz correspond to limits of 140 and 2,240 Hz, respectively, on the full-scale aircraft.

A sound-convection correction was included in the processing of the data so that sources appeared to come from the model rather than being swept downstream. The acoustic sources were depicted, one frequency at a time, as color contours on the scan plane with the model outline superimposed, as shown in Figure 2. Various integration schemes have been developed to compute the combined effects on a listener and to generate narrowband and third-octave acoustic spectra.

Ten airframe noise sources that might be important to approach and landing noise of the full-scale aircraft were identified in the study. The relative strengths of these sources and their dependences on the configuration of the aircraft were documented. Although the data were scaled to the frequencies for the full-scale aircraft, no extrapolation to full-scale flyover was performed.

This work was done by Paul T. Soderman of **Ames Research Center**. *For further information, contact the Ames Technology Partnerships Division at (650) 604-2954.*
ARC-14967

Loci-STREAM Version 0.9

Marshall Space Flight Center, Alabama

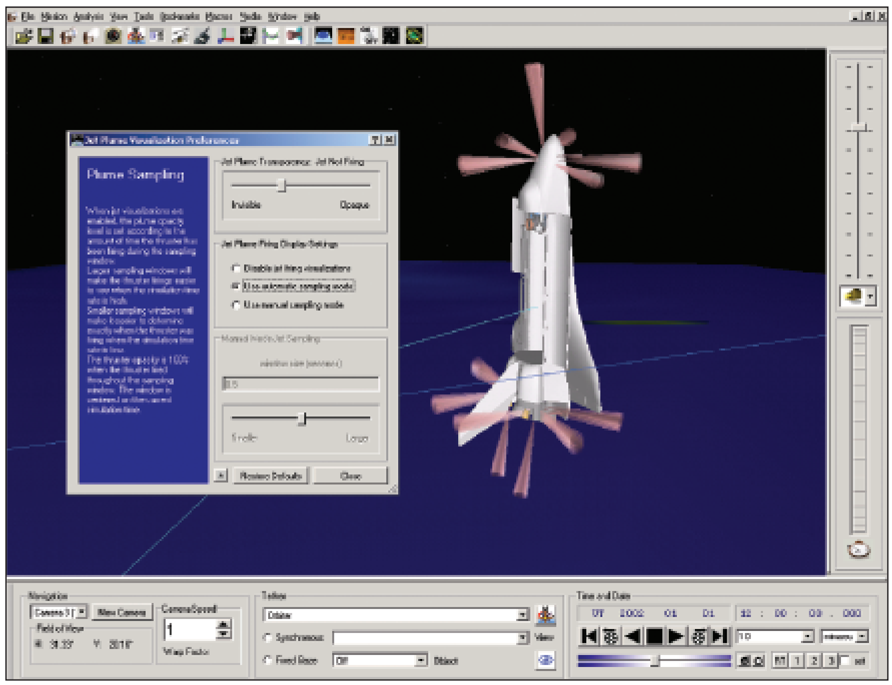
Loci-STREAM is an evolving computational fluid dynamics (CFD) software tool for simulating possibly chemically reacting, possibly unsteady flows in diverse settings, including rocket engines, turbomachines, oil refineries, etc. Loci-STREAM implements a pressure-based flow-solving algorithm that utilizes unstructured grids. (The benefit of low memory usage by pressure-based algorithms is well recognized by experts in the field.) The algorithm is robust for flows at all speeds from zero to hypersonic. The flexibility of arbitrary polyhedral grids enables accurate, efficient simulation of flows in complex geometries, including those of plume-impingement problems. The present version — Loci-STREAM version 0.9 — includes an interface with the Portable, Extensible Toolkit for Scientific Computation (PETSc) library for access to enhanced linear-equation-solving programs therein that accelerate convergence toward a solution. The name "Loci" reflects the creation of this software within the Loci computational framework, which was developed at Mississippi State University for the primary purpose of simplifying the writing of complex multidisciplinary application programs to run in distributed-memory computing environments including clusters of personal computers. Loci has been designed to relieve application programmers of the details of programming for distributed-memory computers.

This program was written by Jeffrey Wright and Siddharth Thakur of Streamline Numerics, Inc. for **Marshall Space Flight Center**. *Further information is contained in a TSP (see page 1).*
MFS-32303-1

The Synergistic Engineering Environment

Langley Research Center, Hampton, Virginia

The Synergistic Engineering Environment (SEE) is a system of software dedicated to aiding the understanding of space mission operations. The SEE can integrate disparate sets of data with analytical capabilities, geometric models of spacecraft, and a visualization environment (see figure), all contributing to the creation of an interactive simulation of spacecraft. Initially designed to satisfy needs pertaining to the International Space Station, the SEE has been broadened in scope to include spacecraft ranging from those in low orbit around the Earth to those on deep-space missions. The SEE includes analytical capabilities in rigid-body dynamics, kinematics, orbital mechanics, and payload operations. These capabilities enable a user to perform real-time interactive engineering analyses focusing on diverse aspects of operations, including flight attitudes and maneuvers, docking of visiting spacecraft, robotic operations, impingement of spacecraft-engine exhaust plumes, obscuration of instrumentation fields of view, communications, and alternative assembly configurations. The SEE continues to undergo development at Langley Research Center.



Plumes of Jet Firings can be displayed by the SEE. The user can turn off the firing visualization without disabling the visualization of the location.

This program was written by Jonathan Cruz of **Langley Research Center** *and Scott Angster of Analytical Mechanics Associates, Inc. Further information is contained in a TSP (see page 1).*
LAR-16842-1

Reconfigurable Software for Controlling Formation Flying

Goddard Space Flight Center, Greenbelt, Maryland

Software for a system to control the trajectories of multiple spacecraft flying in formation is being developed to reflect underlying concepts of (1) a decentralized approach to guidance and control and (2) reconfigurability of the control system, including reconfigurability of the software and of control laws. The software is organized as a modular network of software tasks. The computational load for both determining relative trajectories and planning maneuvers is shared equally among all spacecraft in a cluster. The flexibility and robustness of the software are apparent in the fact that tasks can be added, removed, or replaced during flight. In a computational simulation of a representative formation-flying scenario, it was demonstrated that the following are among the services performed by the software:

- Uploading of commands from a ground station and distribution of the commands among the spacecraft,
- Autonomous initiation and reconfiguration of formations,

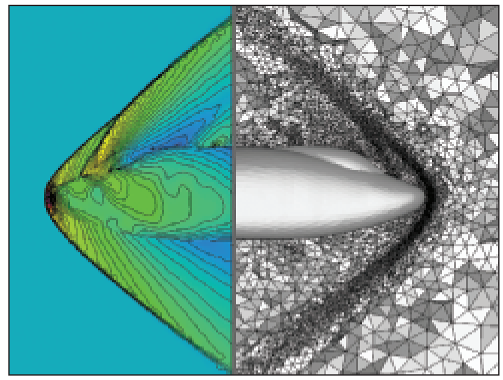
- Autonomous formation of teams through negotiations among the spacecraft,
- Working out details of high-level commands (e.g., shapes and sizes of geometrically complex formations),
- Implementation of a distributed guidance law providing autonomous optimization and assignment of target states, and
- Implementation of a decentralized, fuel-optimal, impulsive control law for planning maneuvers.

This work was done by Joseph B. Mueller of Princeton Satellite Systems, Inc. for **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1). GSC-14779-1*

More About the Tetrahedral Unstructured Software System

Langley Research Center, Hampton, Virginia

TetrUSS is a comprehensive suite of computational fluid dynamics (CFD) programs that won the Software of the Year award in 1996 and has found increasing use in government, academia, and industry for solving realistic flow problems (especially in aerodynamics and aeroelastics of aircraft having complex shapes). TetrUSS includes not only programs for solving basic equations of flow but also programs that afford capabilities for efficient generation and utilization of computational grids and for graphical representation of computed flows (see figure). The 2004 version of the Tetrahedral Unstructured Software System (TetrUSS), which is one of two software systems reported in "NASA's 2004 Software of the Year," *NASA Tech Briefs*, Vol. 28, No. 10 (October 2004), page 18, has been improved greatly since 1996. These improvements include (1) capabilities to simulate viscous flow by solving the Navier-Stokes equations on unstructured grids, (2) portability to personal computers from diverse manufacturers, (3) advanced models of turbulence, (4) a parallel-processing version of one of the unstructured-grid Navier-Stokes-equation-solving programs, and (5) advanced programs for generating unstructured grids.



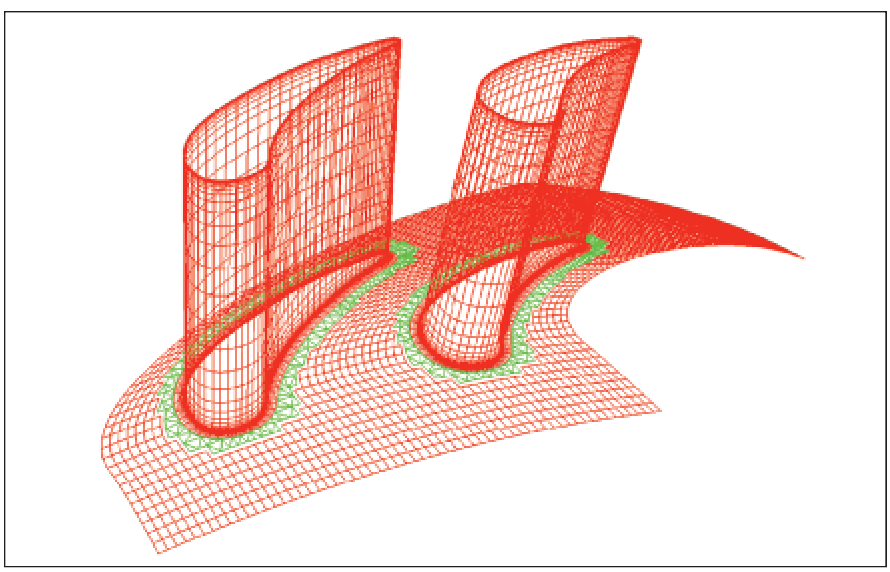
An **Adapted Grid and Flow Solution** are shown on the X-38 vehicle. This is one of the recent features included in TetrUSS.

These programs were written by Khaled S. Abdol-Hamid, Neal T. Frink, Craig A. Hunter, Paresh C. Parikh, Shahyar Z. Pizadeh, and Jamshid A. Samareh of **Langley Research Center***; Maharaj K. Bhat of EITI; Mohagna J. Pandya of Swales Aerospace; and Matthew J. Grismer of the U.S. Air Force Research Laboratory. Further information is contained in a TSP (see page 1). .*
LAR-16882-1

Computing Flows Using Chimera and Unstructured Grids

John H. Glenn Research Center, Cleveland, Ohio

DRAGONFLOW is a computer program that solves the Navier-Stokes equations of flows in complexly shaped three-dimensional regions discretized by use of a direct replacement of arbitrary grid overlapping by nonstructured (DRAGON) grid. A DRAGON grid (see figure) is a combination of a chimera grid (a composite of structured subgrids) and a collection of unstructured subgrids. DRAGONFLOW incorporates modified versions of two prior Navier-Stokes-equation-solving programs: OVERFLOW, which is designed to solve on chimera grids; and USM3D, which is used to solve on unstructured grids. A master module controls the invocation of individual modules in the libraries. At each time step of a simulated flow, DRAGONFLOW is invoked on the chimera portion of the



This is a **DRAGON Grid** of the annular turbine cascade.

DRAGON grid in alternation with USM3D, which is invoked on the unstructured subgrids of the DRAGON grid. The USM3D and OVERFLOW modules then immediately exchange their solutions and other data. As a result, USM3D and OVERFLOW are coupled seamlessly.

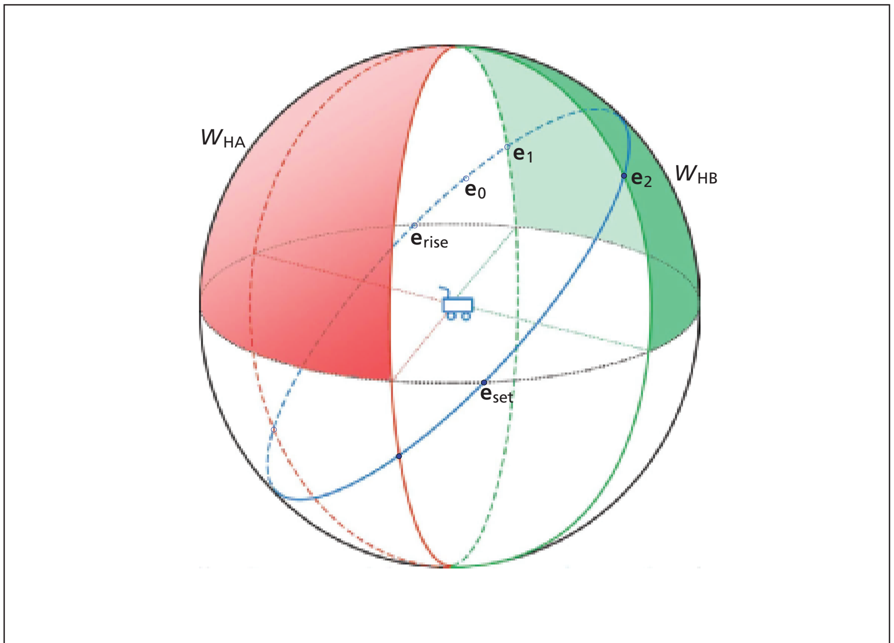
This program was written by Meng-Sing Liou of **Glenn Research Center** *and Yao Zheng of Taitech, Inc. Further information is contained in a TSP (see page 1). .*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17509-1.

Avoiding Obstructions in Aiming a High-Gain Antenna

NASA's Jet Propulsion Laboratory, Pasadena, California

The High Gain Antenna Pointing and Obstruction Avoidance software performs computations for pointing a Mars Rover high-gain antenna for communication with Earth while (1) avoiding line-of-sight obstructions (the Martian terrain and other parts of the Rover) that would block communication and (2) taking account of limits in ranges of motion of antenna gimbals and of kinematic singularities in gimbal mechanisms. The software uses simplified geometric models of obstructions and of the trajectory of the Earth in the Martian sky(see figure). It treats all obstructions according to a generalized approach, computing and continually updating the time remaining before interception of each obstruction. In cases in which the gimbal-mechanism design allows two aiming solutions, the algorithm chooses the solution that provides the longest obstruction-free Earth-tracking time. If the communication session continues until an obstruction is encountered in the current pointing solution and the other solution is now unobstructed, then the algorithm automatically switches to the other position. This software also notifies communication-managing software to cease transmission during the switch to the unobstructed position, resuming it when the switch is complete.



In this **Pointing Strategy Example**, the rover is flat and level on the Martian surface. The Hardstop Occlusions W_{HA} and W_{HB} are indicated as shrouded regions on the celestial sphere. The Earth trajectory as a function of time is depicted by e.

This program was written by Khaled Ali and Charles Vanelli 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42960.

Analyzing Aeroelastic Stability of a Tilt-Rotor Aircraft

Langley Research Center, Hampton, Virginia

Proprotor Aeroelastic Stability Analysis, now at version 4.5 (PASTA 4.5), is a FORTRAN computer program for analyzing the aeroelastic stability of a tilt-rotor aircraft in the airplane mode of flight. The program employs a 10-degree-of-freedom (DOF), discrete-coordinate, linear mathematical model of a rotor with three or more blades and its drive system coupled to a 10-DOF modal model of an airframe. The user can select which DOFs are included in the analysis. Quasi-steady strip-theory aerodynamics is employed for the aerodynamic loads on the blades, a quasi-steady representation is employed for the aerodynamic loads acting on the vibrational modes of the airframe, and a stability-derivative approach is used for the aerodynamics associated with the rigid-body DOFs of the airframe. Blade parameters that vary with the blade collective pitch can be obtained by interpolation from a user-defined table. Stability is determined by examining the eigenvalues that are obtained by solving the coupled equations of motions as a matrix eigenvalue problem. Notwithstanding the relative simplicity of its mathematical foundation, PASTA 4.5 and its predecessors have played key roles in a number of engineering investigations over the years.

This program was written by Raymond G. Kvaternik of **Langley Research Center**. *Further information is contained in a TSP (see page 1).* *LAR-17175-1*

Tracking Positions and Attitudes of Mars Rovers

NASA's Jet Propulsion Laboratory, Pasadena, California

The Surface Attitude Position and Pointing (SAPP) software, which runs on computers aboard the Mars Exploration Rovers, tracks the positions and attitudes of the rovers on the surface of Mars. Each rover acquires data on attitude from a combination of accelerometer readings and images of the Sun acquired autonomously, using a pointable camera to search the sky for the Sun. Depending on the nature of movement commanded remotely by operators on Earth, the software propagates attitude and position by use of either (1) accelerometer and gyroscope readings or (2) gyroscope readings and wheel odometry. Where necessary, visual odometry is performed on images to fine-tune the position updates, particularly on high-wheel-slip terrain. The attitude data are used by other software and ground-based personnel for pointing a high-gain antenna, planning and execution of driving, and positioning and aiming scientific instruments.

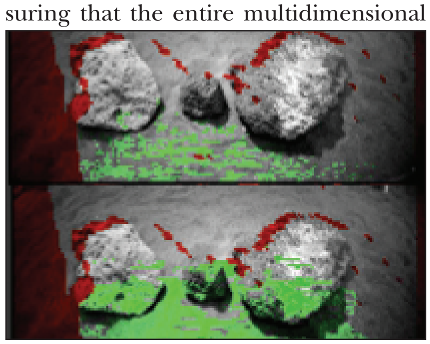
This work was done by Khaled Ali, Charles Vanelli, Jeffrey Biesiadecki, Alejandro San Martin, Mark Maimone, Yang Cheng, and James Alexander of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41876.

Stochastic Evolutionary Algorithms for Planning Robot Paths

NASA's Jet Propulsion Laboratory, Pasadena, California

A computer program implements stochastic evolutionary algorithms for planning and optimizing collision-free paths for robots and their jointed limbs. Stochastic evolutionary algorithms can be made to produce acceptably close approximations to exact, optimal solutions for path-planning problems while often demanding much less computation than do exhaustive-search and deterministic inverse-kinematics algorithms that have been used previously for this purpose. Hence, the present software is better suited for application aboard robots having limited computing capabilities (see figure). The stochastic aspect lies in the use of simulated annealing to (1) prevent trapping of an optimization algorithm in local minima of an energy-like error measure by which the fitness of a trial solution is evaluated while (2) ensuring that the entire multidimensional configuration and parameter space of the path-planning problem is sampled efficiently with respect to both robot joint angles and computation time. Simulated annealing is an established technique for avoiding local minima in multidimensional optimization problems, but has not, until now, been applied to planning collision-free robot paths by use of low-power computers.



A comparison of **Digital Terrain Maps** shows reachability of targets with the FIDO robotic arm. Green (light) areas are reachable, with arm path solutions. Grey areas are not reachable and red (dark) areas indicate no data available for a solution. (Note: FIDO is Field Integrated Design and Operations.)

This program was written by Wolfgang Fink, Hrand Aghazarian, Terrance Huntsberger, and Richard Terrile 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42206.

Compressible Flow Toolbox

John H. Glenn Research Center, Cleveland, Ohio

The Compressible Flow Toolbox is primarily a MATLAB-language implementation of a set of algorithms that solve approximately 280 linear and nonlinear classical equations for compressible flow. The toolbox is useful for analysis of one-dimensional steady flow with either constant entropy, friction, heat transfer, or Mach number >1. The toolbox also contains algorithms for comparing and validating the equation-solving algorithms against solutions previously published in open literature. The classical equations solved by the Compressible Flow Toolbox are as follows:

- The isentropic-flow equations,
- The Fanno flow equations (pertaining to flow of an ideal gas in a pipe with friction),
- The Rayleigh flow equations (pertaining to frictionless flow of an ideal gas, with heat transfer, in a pipe of constant cross section),
- The normal-shock equations,
- The oblique-shock equations, and
- The expansion equations.

This program was written by Kevin J. Melcher 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:

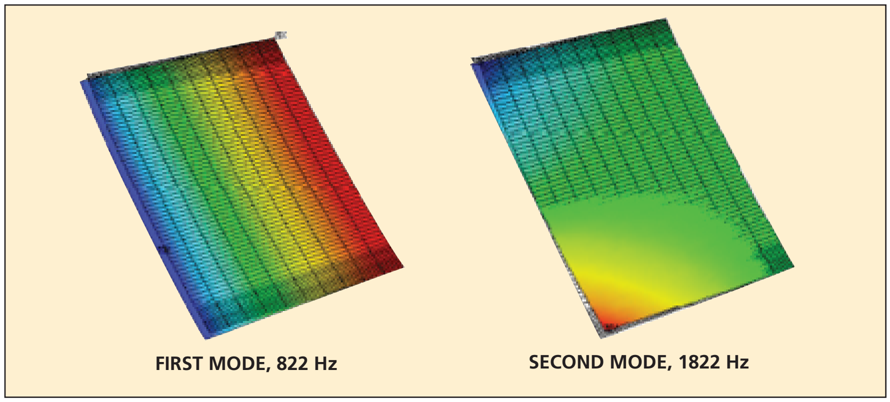
NASA Glenn Research Center
Innovative Partnerships Office
Attn: Steve Fedor
Mail Stop 4–8
21000 Brookpark Road
Cleveland, Ohio 44135.

Refer to LEW-17898-1.

Rapid Aeroelastic Analysis of Blade Flutter in Turbomachines

John H. Glenn Research Center, Cleveland, Ohio

The LINFLUX-AE computer code predicts flutter and forced responses of blades and vanes in turbomachines under subsonic, transonic, and supersonic flow conditions. The code solves the Euler equations of unsteady flow in a blade passage under the assumption that the blades vibrate harmonically at small amplitudes. The steady-state nonlinear Euler equations are solved by a separate program, then equations for unsteady flow components are obtained through linearization around the steady-state solution. A structural-dynamics analysis (see figure) is performed to determine the frequencies and mode shapes of blade vibrations, a preprocessor interpolates mode shapes from the structural-dynamics mesh onto the LINFLUX computational-fluid-dynamics mesh, and an interface code is used to convert the steady-state flow solution to a form required by LINFLUX. Then LINFLUX solves the linearized equations in the frequency domain to calculate the unsteady aerodynamic pressure distribution for a given vibration mode, frequency, and interblade phase angle.



Blade Mode Shapes are shown for first and second modes. The first mode is a bending mode at 822 Hz, and the second mode is a torsion mode at 1,882 Hz.

A postprocessor uses the unsteady pressures to calculate generalized aerodynamic forces, response amplitudes, and eigenvalues (which determine the flutter frequency and damping). In comparison with the TURBO-AE aeroelastic-analysis code, which solves the equations in the time domain, LINFLUX-AE is 6 to 7 times faster.

This program was written by J. J. Trudell, O. Mehmed, G. L. Stefko, and M. A. Bakhle of **Glenn Research Center***; T. S. R. Reddy of the University of Toledo; M. Montgomery of United Technologies; and J. Verdon of Ohio Aerospace Institute. 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, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17880-1.

General Flow-Solver Code for Turbomachinery Applications

Marshall Space Flight Center, Alabama

Phantom is a computer code intended primarily for real-fluid turbomachinery problems. It is based on Corsair, an ideal-gas turbomachinery code, developed by the same authors, which evolved from the ROTOR codes from NASA Ames. Phantom is applicable to real and ideal fluids, both compressible and incompressible, flowing at subsonic, transonic, and supersonic speeds. It utilizes structured, overset, O- and H-type zonal grids to discretize flow fields and represent relative motions of components. Values on grid boundaries are updated at each time step by bilinear interpolation from adjacent grids. Inviscid fluxes are calculated to third-order spatial accuracy using Roe's scheme. Viscous fluxes are calculated using second-order-accurate central differences. The code is second-order accurate in time. Turbulence is represented by a modified Baldwin-Lomax algebraic model. The code offers two options for determining properties of fluids: One is based on equations of state, thermodynamic departure functions, and corresponding state principles. The other, which is more efficient, is based on splines generated from tables of properties of real fluids. Phantom currently contains fluid-property routines for water, hydrogen, oxygen, nitrogen, kerosene, methane, and carbon monoxide as well as ideal gases.

This work was done by Daniel Dorney of **Marshall Space Flight Center** *and Douglas Sondak of Boston University. Further information is contained in a TSP (see page 1). MFS-32321-1*

Code for Multiblock CFD and Heat-Transfer Computations

John H. Glenn Research Center, Cleveland, Ohio

The NASA Glenn Research Center General Multi-Block Navier-Stokes Convective Heat Transfer Code, Glenn-HT, has been used extensively to predict heat transfer and fluid flow for a variety of steady gas turbine engine problems. Recently, the Glenn-HT code has been completely rewritten in Fortran 90/95, a more object-oriented language that allows programmers to create code that is more modular and makes more efficient use of data structures. The new implementation takes full advantage of the capabilities of the Fortran 90/95 programming language. As a result, the

Glenn-HT code now provides dynamic memory allocation, modular design, and unsteady flow capability. This allows for the heat-transfer analysis of a full turbine stage. The code has been demonstrated for an unsteady inflow condition, and gridding efforts have been initiated for a full turbine stage unsteady calculation. This analysis will be the first to simultaneously include the effects of rotation, blade interaction, film cooling, and tip clearance with recessed tip on turbine heat transfer and cooling performance. Future plans call for the application of the new Glenn-HT code to a range of gas turbine engine problems of current interest to the heat-transfer community. The new unsteady flow capability will allow researchers to predict the effect of unsteady flow phenomena upon the convective heat transfer of turbine blades and vanes. Work will also continue on the development of conjugate heat-transfer capability in the code, where simultaneous solution of convective and conductive heat-transfer domains is accomplished. Finally, advanced turbulence and fluid flow models and automatic gridding techniques are being developed that will be applied to the Glenn-HT code and solution process.

This program was written by John C. Fabian, James D. Heidmann, and Barbara L. Lucci of **Glenn Research Center***; Ali A. Ameri of the University of Toledo; David L. Rigby of QSS, Inc.; and Erlendur Steinthorsson A & E Consulting, Inc. 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, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17914-1.

Machinery/Automation

Rotating-Pump Design Code

John H. Glenn Research Center, Cleveland, Ohio

Pump Design (PUMPDES) is a computer program for designing a rotating pump for liquid hydrogen, liquid oxygen, liquid nitrogen, water, methane, or ethane. Using realistic properties of these fluids provided by another program called "GASPAK," this code performs a station-by-station, mean-line analysis along the pump flow path, obtaining thermodynamic properties of the pumped fluid at each station and evaluating hydraulic losses along the flow path. The variables at each station are obtained under constraints that are consistent with the underlying physical principles. The code evaluates the performance of each stage and the overall pump. In addition, by judiciously choosing the givens and the unknowns, the code can perform a geometric inverse design function: that is, it can compute a pump geometry that yields a closest approximation of given design point. The code contains two major parts: one for an axial-rotor/inducer and one for a multistage centrifugal pump. The inducer and the centrifugal pump are functionally integrated. The code can be used in designing and/or evaluating the inducer/centrifugal-pump combination or the centrifugal pump alone. The code is written in standard Fortran 77.

This program was written by James F. Walker and Shu-Cheng Chen of **Glenn Research Center** *and Dean D. Scheer of Sverdrup Technology, Inc. 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, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17576-1.

Manufacturing & Prototyping

Covering a Crucible With Metal Containing Channels

Metal is deposited on a sacrificial pattern that defines the channels.

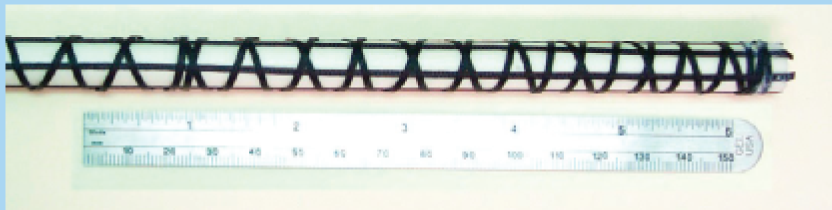
Marshall Space Flight Center, Alabama

In a procedure that partly resembles the lost-wax casting process, a crucible made of a brittle material (ceramic, quartz, or glass) is covered with a layer of metal containing channels. The metal cover and the channels can serve any or all of several purposes, depending upon the application: Typically, the metal would serve at least partly to reinforce the crucible. The channels could be used as passages for narrow objects that could include thermocouples and heat-transfer strips. Alternatively or in addition, channels could be used as flow paths for liquid or gaseous coolants and could be positioned and oriented for position- or direction-selective cooling. In some cases, the channels could be filled with known gases and sealed so that failure of the crucibles could be indicated by instruments that detect the gases.

The process consists of three main steps. In the first step, a pattern defining the channels is formed by wrapping or depositing a material in the desired channel pattern on the outer surface of the crucible. The pattern material can be a plastic, wax, low-ash fibrous material, a soluble material, or other suitable material that can subsequently be removed easily. In a proof-of-concept demonstration (see figure), the crucible was an alumina cylinder and the mold material was plastic tie-down tape.

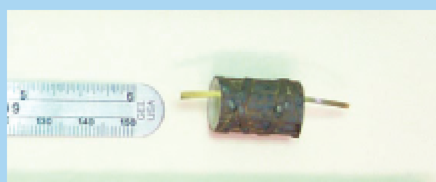
In the second step, the patterned crucible is coated with metal. In one variation of the second step, a very thin layer containing or consisting of an electrically conductive material (e.g., gold, silver, or carbon) is painted or otherwise deposited on the mold-covered crucible, then the covering metal required for the specific application is electrodeposited on the very thin conducting layer. In another variation of the second step, the metal coat is formed by chemical vapor deposition. In the proof-of-concept demonstration, a layer of nickel 0.003 in. (≈0.08 mm) thick was electrodeposited.

In the third step, the patterned material is removed. This is generally done by heating the crucible assembly until the patterned material melts and runs out, vaporizes, and/or decomposes to an ash, leaving the channels. Alternatively, if the patterned material is soluble, it can be removed by use of a suitable solvent. In the proof-of-concept demonstration, the tape was burned away by heating the assembly to a temperature of 600 °C.



Plastic Tie-Down Tape Wrapped Around Alumina.

Wrapped Crucible After Plating With 0.003 Inch of Nickel.



Part of the Plated Crucible After Removal of the Tape With a Piece of Brass Sheet Threaded Through One of the Channels

Plastic Tie-Down Tape was wrapped around an alumina crucible, the tape-wrapped crucible was electroplated with nickel, then the tape was burned out, leaving nickel-walled passages covering the crucible.

This work was done by Richard N. Grugel of **Marshall Space Flight Center**. *Further information is contained in a TSP (see page 1).*

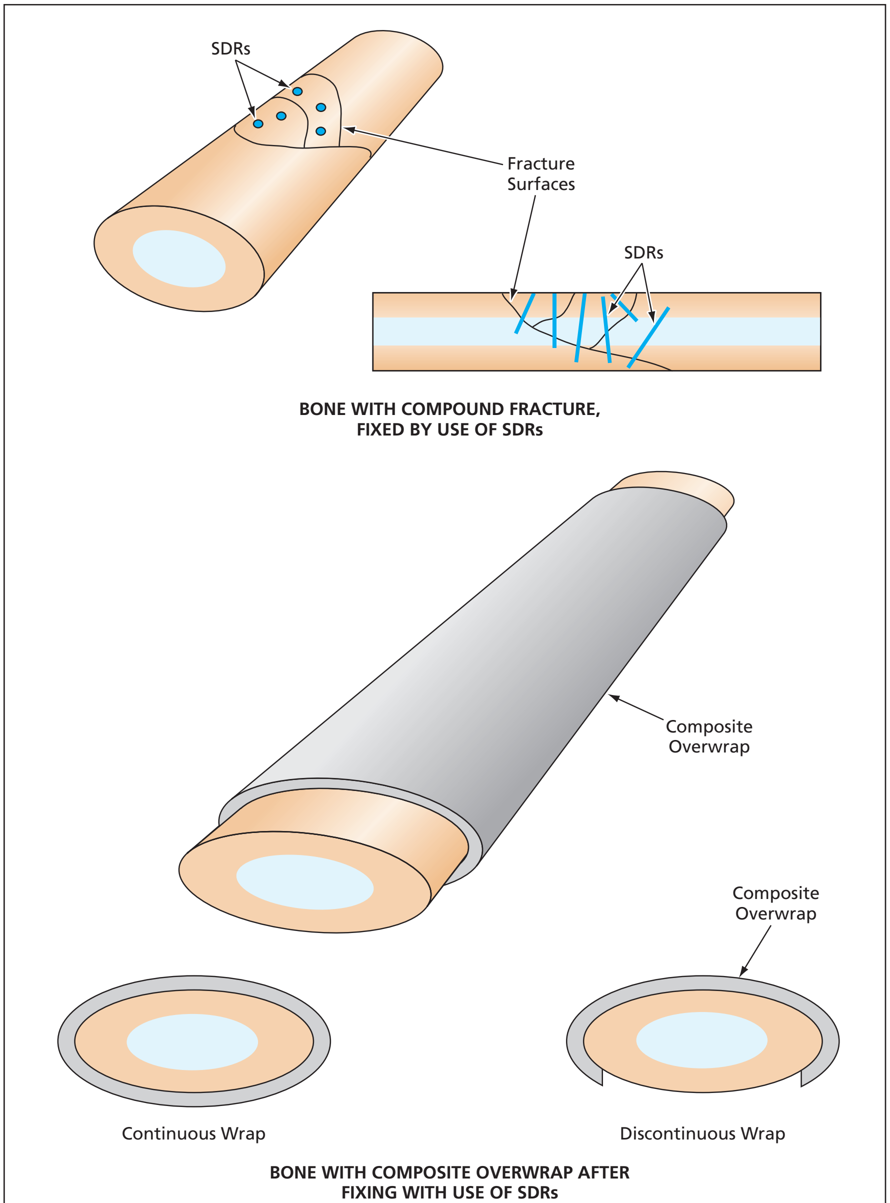
This invention has been patented by NASA (U.S. Patent No. 6,802,999). Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-31698-1.

Repairing Fractured Bones by Use of Bioabsorbable Composites

Less surgery would be necessary, and full strength would be restored sooner.

Langley Research Center, Hampton, Virginia

A proposed method of surgical repair of fractured bones would incorporate recent and future advances in the art of composite materials. The composite materials used in this method would be biocompatible and at least partly bioabsorbable: that is, during the healing process following surgery, they would be wholly or at least partly absorbed into the bones and other tissues in which they were implanted. Relative to the traditional method, the proposed method would involve less surgery, pose less of a risk of infection, provide for better transfer of loads across fracture sites, and thereby promote better healing while reducing the need for immobilization by casts and other external devices.



SDRs Would Be Driven Like Nails through adjacent segments of a fractured bone. By use of two or more SDRs oriented at different angles, the segments would become locked together. The fractured bone would be further immobilized by an overwrapped composite-material shell.

One requirement that both the traditional and proposed methods must satisfy is to fix the multiple segments of a broken bone in the correct relative positions. Mechanical fixing techniques used in the traditional method include the use of plates spanning the fracture site and secured to the bone by screws, serving of wire along the bone across the fracture site, insertion of metallic intramedullary rods through the hollow portion of the fractured bone, and/or inserting transverse rods through the bone, muscle, and skin to stabilize the fractured members. After the bone heals, a second surgical operation is needed to remove the mechanical fixture(s). In the proposed method, there would be no need for a second surgical operation.

The proposed method is based partly on the observation that in the fabrication of a structural member, it is generally more efficient and reliable to use multiple small fasteners to transfer load across a joint than to use a single or smaller number of larger fasteners, provided that the stress fields of neighboring small fasteners do not overlap or interact. Also, multiple smaller fasteners are more reliable than are larger and fewer fasteners. However, there is a trade-off between structural efficiency and the cost of insertion time and materials.

The proposed method is further based partly on the conjecture that through-the-thickness reinforcements could be excellent for fixing bone segments for surgical repair. The through-the-thickness reinforcements would superficially resemble nails in both form and function. Denoted small-diameter rods (SDRs) to distinguish them from other narrow rods, these reinforcements would be shot or otherwise inserted through adjacent segments of fractured bone to fix them in their correct relative positions (see figure). Shot insertion would be effected by use an applicator that would amount to a miniaturized and highly refined version of the pneumatic guns often used in carpentry to drive nails and brads. The applicator, envisioned to be about the size of a ball-point-pen, would be driven by pressurized carbon dioxide. To further promote stabilization of the segments, layers of bone glue could be applied to the fracture surfaces prior to insertion of the SDRs. The bone glue could be therapeutically loaded with chemicals to promote growth of bone and fight infection.

SDRs would be produced in a variety of diameters to suit specific applications. Typical diameters are expected to range from 0.02 to 0.1 in. (about 0.5 to 2.5 mm). An SDR could be fabricated as a matrix/fiber composite material: The fibers could be made of a biocompatible glass or polymer, and the matrix would be made of a bioabsorbable material that could be therapeutically loaded with bone-growth and infection-fighting chemicals. Optionally, the fibers could be made of a bioabsorbable material, so that in time, nothing of the SDR would remain in the healed bone. Yet another option would be to fabricate an SDR as a metal tube containing bone-growth and infection-fighting chemicals that would leach out through pores.

Once the bone segments were fixed in place by insertion of SDRs, additional structural support and immobilization would be provided by wrapping and co-curing a multilayer composite-material shell around the outer surface of the fractured bone. This shell would be made of a fabric preimpregnated with a curable, bioabsorbable matrix resin. From a purely structural perspective, it would be preferable to form the shell around the entire circumference of the bone; from a surgical perspective, it could be more practical to form the shell part way around the circumference and strengthen the bone by use additional SDRs.

The curing of the composite would create a rigid structural element integrally bonded to the bone. The combination of the SDRs and the composite shell may be sufficient to restore the bone to its original strength, or nearly so. Hence, there would be little or no need for a cast or other external immobilizing device. At the least, the amount of time the patient must wait before returning to normal activity should be less than it would be if the repair were performed by the traditional method.

This work was done by Gary L. Farley of the U. S. Army Research Laboratory for **Langley Research Center**. *Further information is contained in a TSP (see page 1). LAR-16354-1*

Physical Sciences

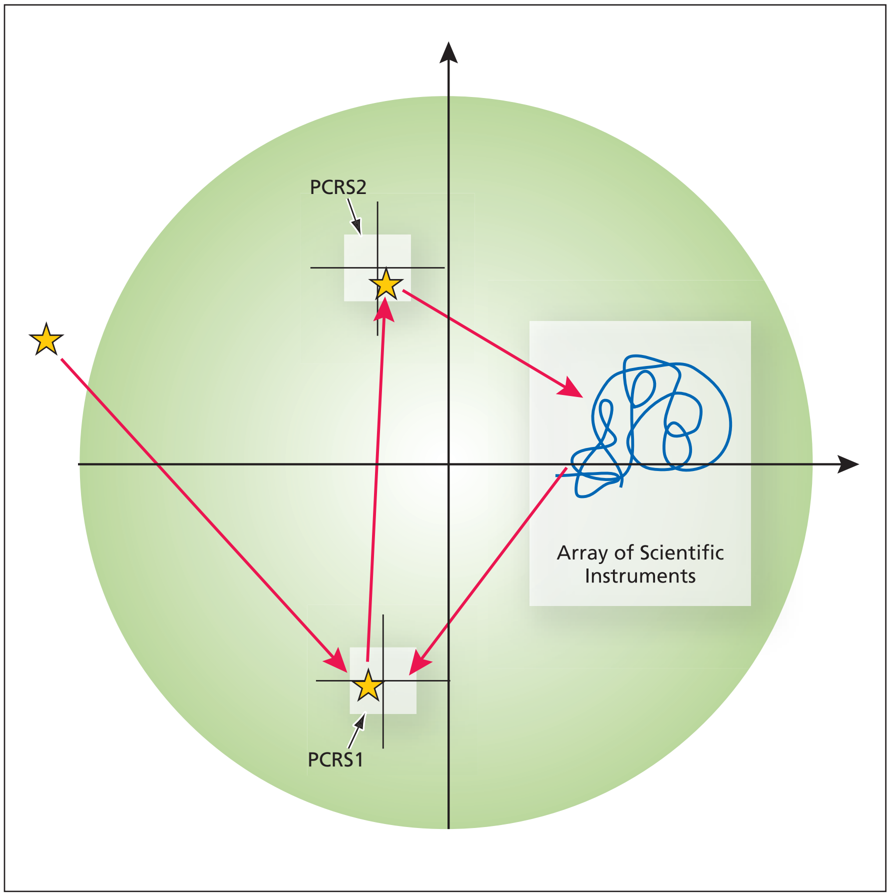
Kalman Filter for Calibrating a Telescope Focal Plane

Optimal estimates of scientific and engineering calibration parameters are generated simultaneously.

NASA's Jet Propulsion Laboratory, Pasadena, California

The instrument-pointing frame (IPF) Kalman filter, and an algorithm that implements this filter, have been devised for calibrating the focal plane of a telescope. As used here, "calibration" signifies, more specifically, a combination of measurements and calculations directed toward ensuring accuracy in aiming the telescope and determining the locations of objects imaged in various arrays of photodetectors in instruments located on the focal plane. The IPF Kalman filter was originally intended for application to a spaceborne infrared astronomical telescope, but can also be applied to other spaceborne and ground-based telescopes.

In the traditional approach to calibration of a telescope, (1) one team of experts concentrates on estimating parameters (e.g., pointing alignments and gyroscope drifts) that are classified as being of primarily an engineering nature, (2) another team of experts concentrates on estimating calibration parameters (e.g., plate scales and optical distortions) that are classified as being primarily of a scientific nature, and (3) the two teams repeatedly exchange data in an iterative process in which each team refines its estimates with the help of the data provided by the other team. This iterative process is inefficient and uneconomical because it is time-consuming and entails the maintenance of two survey teams and the development of computer programs specific to the requirements of each team. Moreover, theoretical analysis reveals that the engineering/science iterative approach is not optimal in that it does not yield the best estimates of focal-plane parameters and, depending on the application, may not even enable convergence toward a set of estimates.



The **Focal Plane Is Occupied** by two pointing-control reference sensors (PCRSs) and an array of scientific instruments. The telescope is maneuvered so that a star is first centroided on PCRS1, then centroided on PCRS2, then moved over to the array of scientific instruments to obtain a series of centroid measurements, then centroided again on PCRS1. This maneuver makes it possible to attain the main goal of the calibration, which is to establish the locations of the instruments in a telescope-pointing reference frame.

In contrast, in the IPF Kalman-filter approach, no attempt is made to distinguish between engineering and scientific parameters. Hence, there is no need for separate engineering and scientific survey teams, separate software, and iteration between the teams. Instead, both engineering and scientific focal-plane parameters are estimated together, using data taken in the same focal-plane survey. The main advantage is that the IPF Kalman filter offers greater efficiency and economy. In addition, the estimates generated by the IPF Kalman filter are optimal.

The IPF Kalman filter is a high-order square-root iterated linearized Kalman filter, which offers robust numerical conditioning and a capability to obtain high accuracy. The filter is parameterized for calibrating the focal plane and aligning the scientific-instrument photodetector arrays with respect to the telescope boresight, all to within a specified tolerance (in the original intended application, a focal-plane radial standard deviation corresponding to 0.14 arc second in the sky). To obtain this level of accuracy, the filter utilizes 37 states to estimate desired alignments while also correcting for systematic errors expected to be caused by optical distortions, the scale factor and misalignment of a scanning mirror, thermomechanically induced drifts of alignments among telescope and instrument frames, and gyroscope bias and bias drift in all axes.

Other salient features of the IPF Kalman filter and algorithm include the following:

- The use of polynomial functions of time to characterize such time-dependent behaviors as gyroscope drifts and thermomechanically induced alignment drifts. Because the polynomial coefficients are constant, this feature makes it possible to accommodate such behaviors while retaining the global re-linearization of the Kalman filter.

- A gyroscope-data pre-processing subalgorithm makes it possible to compute and store gyroscope sensitivities in advance, thereby eliminating the need for repeated and time-consuming propagation of gyroscope sensitivities during each filter cycle.
- A parameter-masking capability offers the option of restricting estimation to an arbitrary subset of all the focal-plane parameters, thereby affording flexibility to match calibration mathematical models of different levels of fidelity to different scientific instruments.
- A "multi-run" feature affords flexibility to estimate parameters by use of measurement data, which has been acquired during different observing sessions.
- An experiment design characterized by maneuvers illustrated in the figure provides for observability of all desired parameters and enables the use of the same Kalman filter for a variety of instruments.
- Measurements using observations of both visible and infrared sources can be included in the same set of calibration data.
- There is an option to process centroid information that is partial in the sense that it pertains only to position along a single axis of a photodetector array. Such information is obtained, for example, when calibrating the entrance aperture of spectrometer slit by first scanning a source across the narrow slit width, and then scanning the source along its length.
- The filter algorithm can be executed in one of several optional modes that offer compromises between accuracy and robustness.

This work was done by Bryan Kang and David Bayard of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-40798

Electronic Absolute Cartesian Autocollimator

Readout is not materially affected by drifts in analog circuitry.

Goddard Space Flight Center, Greenbelt, Maryland

An electronic absolute Cartesian autocollimator performs the same basic optical function as does a conventional all-optical or a conventional electronic autocollimator but differs in the nature of its optical target and the manner in which the position of the image of the target is measured. The term "absolute" in the name of this apparatus reflects the nature of the position measurement, which, unlike in a conventional electronic autocollimator, is based absolutely on the position of the image rather than on an assumed proportionality between the position and the levels of processed analog electronic signals. The term "Cartesian" in the name of this apparatus reflects the nature of its optical target.

Figure 1 depicts the electronic functional blocks of an electronic absolute Cartesian autocollimator along with its basic optical layout, which is the same as that of a conventional autocollimator. Referring first to the optical layout and functions only, this or any autocollimator is used to measure the compound angular deviation of a flat datum mirror with respect to the optical axis of the autocollimator itself. The optical components include an illuminated target, a beam splitter, an objective or collimating lens, and a viewer or detector (described in more detail below) at a viewing plane. The target and the viewing planes are focal planes of the lens. Target light reflected by the datum mirror is imaged on the viewing plane at unit magnification by the collimating lens.

If the normal to the datum mirror is parallel to the optical axis of the autocollimator, then the target image is centered on the viewing plane. Any angular deviation of the normal from the optical axis manifests itself as a lateral displacement of the target image from the center. The magnitude of the displacement is proportional to the focal length and to the magnitude (assumed to be small) of the angular deviation. The direction of the displacement is perpendicular to the axis about which the mirror is slightly tilted. Hence, one can determine the amount and direction of tilt from the coordinates of the target image on the viewing plane.

In a conventional all-optical autocollimator, the target is a first reticle, a technician observes the target image through an eyepiece, and a second reticle affixed to the viewing plane is used to measure the coordinates of the displaced image of the first reticle. In a conventional electronic autocollimator (which could be characterized more accurately as a conventional optoelectronic autocollimator), the target is a pinhole and a position-sensitive photodetector is placed at the viewing plane. The location of the bright pinhole image is measured by use of the position-sensitive photodetector along with analog readout circuits. The net outputs of these circuits are two sets of voltage differences nominally proportional to the displacement of the pinhole image along two coordinate axes (x and y) in the viewing plane. Like all analog devices and circuits, the position-sensitive photodetector and its readout circuits exhibit thermal and spontaneous drifts,

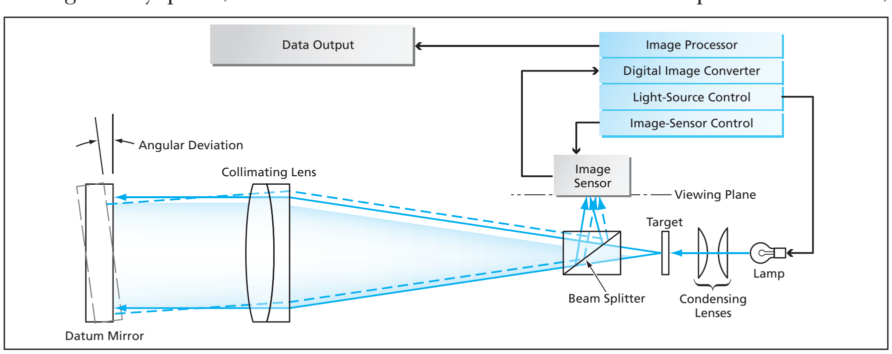


Figure 1. An **Electronic Absolute Cartesian Autocollimator** includes a conventional autocollimator optical system with a coded Cartesian-grid target, an image sensor, and a digital image-processing and control system.

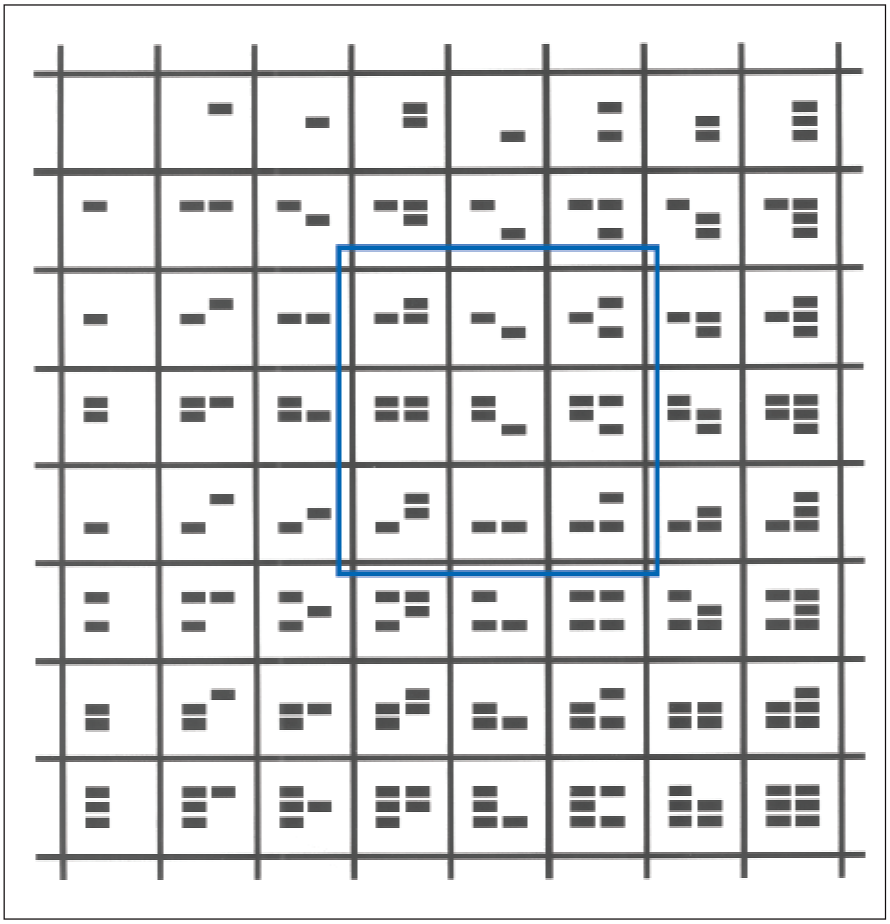


Figure 2. In the **Coded Cartesian Grid**, each grid cell contains a distinct binary image code that identifies that cell. The upper code bits in a cell identify the line at the bottom of the cell, while the lower bits identify the line at the left of the cell. In the instantaneous field of regard (square box), code bits identify vertical lines 2, 3, and 4, and horizontal lines 3, 4, and 5.

which contribute to errors and lack of stability in position measurements. Nonuniformity of the position-sensitive photodetector also contributes to readout nonlinearity.

In the electronic absolute Cartesian autocollimator, the target is a coded Cartesian grid (see Figure 2) and the viewing plane is occupied by an image sensor. Vertical lines in the target image encode azimuthal deflections of the datum mirror from the optical axis, while horizontal lines encode elevational deflections. The planar array of pixels of the image sensor intrinsically constitutes a fixed high-resolution coordinate grid. The outputs from the pixels are digitized, and the resulting digital data are processed to decipher the codes in the target image and to determine locations of centroids of grid lines, which provide angular measurement with a granularity nearly one thousand times finer than the angular extent of a single pixel. Each centroid produces an independent position measurement. Averaging measurements together naturally increases readout accuracy and sensitivity.

The combination of the intrinsic grid structure of the image sensor and the Cartesian grid of the target image ensures linearity of output and a high degree of immunity to any non-uniformity among responses of individual sensor pixels. The coding of the grid ensures unambiguous position readout.

Processing of the target image is not subject to drift as a result of weakness of signals on the image sensor. At worst, weakness of signals increases the proportion of noise. Therefore, the electronic absolute Cartesian autocollimator includes a servo loop that regulates the brightness of illumination to keep signal levels optimum. Finally, the electronic absolute Cartesian autocollimator offers one major additional advantage over a conventional electronic autocollimator: The cells of the Cartesian grid effectively constitute a multiplicity of targets that, collectively, makes the field of regard of this apparatus much larger than that of a conventional electronic autocollimator.

This work was done by Douglas B. Leviton of **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*

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, Goddard Space Flight Center, (301) 286-7351. Refer to GSC-14718-1.

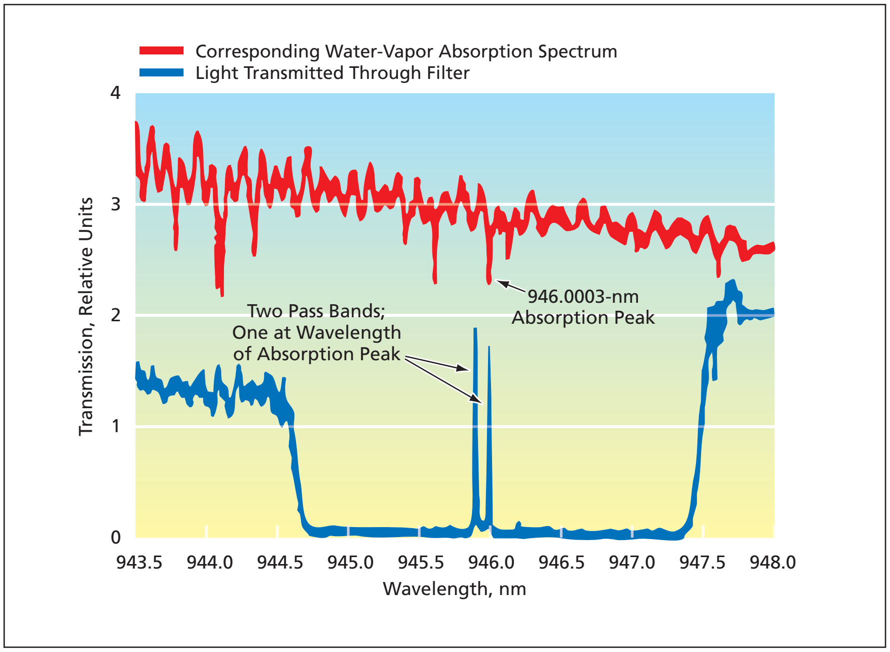
Fiber-Optic Gratings for Lidar Measurements of Water Vapor

These are highly selective, lightweight, tunable optical filters.

Langley Research Center, Hampton, Virginia

Narrow-band filters in the form of phase-shifted Fabry-Perot Bragg gratings incorporated into optical fibers are being developed for differential-absorption lidar (DIAL) instruments used to measure concentrations of atmospheric water vapor. The basic idea is to measure the relative amounts of pulsed laser light scattered from the atmosphere at two nearly equal wavelengths, one of which coincides with an absorption spectral peak of water molecules and the other corresponding to no water vapor absorption. As part of the DIAL measurement process, the scattered light is made to pass through a filter on the way to a photodetector. Omitting other details of DIAL for the sake of brevity, what is required of the filter is to provide a stop band that:

- Surrounds the water-vapor spectral absorption peaks at a wavelength of ≈946 nm,
- Has a spectral width of at least a couple of nanometers,
- Contains a pass band preferably no wider than necessary to accommodate the 946.0003-nm-wavelength water-



The **Transmission Spectrum** of a prototype filter was found to contain the desired two narrow pass bands within a stop band and was tension-tuned to match the 946-nm water vapor absorption line.

vapor absorption peak [which has 8.47 pm full width at half maximum (FWHM)], and

- Contains another pass band at the slightly shorter wavelength of 945.9 nm, where there is scattering of light from aerosol particles but no absorption by water molecules.

Whereas filters used heretofore in DIAL have had bandwidths of ≈300 pm, recent progress in the art of fiber-optic Bragg-grating filters has made it feasible to reduce bandwidths to ≤20 pm and thereby to reduce background noise. Another benefit of substituting fiber-optic Bragg-grating filters for those now in use would be significant reductions in the weights of DIAL instruments. Yet another advantage of fiber-optic Bragg-grating filters is that their transmission spectra can be shifted to longer wavelengths by heating or stretching: hence, it is envisioned that future DIAL instruments would contain devices for fine adjustment of transmission wavelengths through stretching or heating of fiber-optic Bragg-grating filters nominally designed and fabricated to have transmission wavelengths that, in the absence of stretching, would be slightly too short.

Prototype fiber-optic Bragg-grating filters were designed so that their grating structures were chirped and each filter included π-radian phase shifts at two locations along its length. In each filter, the chirp was characterized by 200 uniform-pitch fields concatenated along a total length of about 6 cm. The chirp rate was 0.3 nm/cm, with a pitch centered at 648.9 nm. The π-radian phase shifts were located at lengthwise positions of 29 and 31 cm, respectively. The particular combination of chirping parameters and phase-shift locations was chosen to yield the desired pass bands at wavelengths of 945.9 and 946.0003 nm in a stop band 2.66 nm wide upon stretching of the fiber at a tension equivalent to the terrestrial weight of a mass of 140 mg (see figure). The filters were fabricated in a multistep process, starting with electron-beam patterning of step-chirp corrugations into a mask. Hydrogen-loaded single-mode optical fibers were irradiated through the mask by light from an ultraviolet excimer laser, then the fibers were annealed by heating.

The prototype fiber-optic Bragg-grating filters were subjected to several tests that demonstrated their potential utility for DIAL water-vapor measurements. Measurements of the transmission spectra of the filters were found to be well approximated by theoretical calculations, which were made by use of a piecewise-matrix form of a coupled-mode equation. Tension tuning was also demonstrated.

This work was done by Leila B. Vann and Russell J. DeYoung of **Langley Research Center** *and Stephen J. Mihailov, Ping Lu, Dan Grobnic, and Robert Walker of the Communications Research Centre Canada. Further information is contained in a TSP (see page 1). LAR-17039-1*

Simulating Responses of Gravitational-Wave Instrumentation

NASA's Jet Propulsion Laboratory, Pasadena, California

Synthetic LISA is a computer program for simulating the responses of the instrumentation of the NASA/ESA Laser Interferometer Space Antenna (LISA) mission, the purpose of which is to detect and study gravitational waves. Synthetic LISA generates synthetic time series of the LISA fundamental noises, as filtered through all the time-delay-interferometry (TDI) observables. (TDI is a method of canceling phase noise in temporally varying unequal-arm interferometers.) Synthetic LISA provides a streamlined module to compute the TDI responses to gravitational waves, according to a full model of TDI (including the motion of the LISA array and the temporal and directional dependence of the arm lengths). Synthetic LISA is written in the C++ programming language as a modular package that accommodates the addition of code for specific gravitational wave sources or for new noise models. In addition, time series for waves and noises can be easily loaded from disk storage or electronic memory. The package includes a Python-language interface for easy, interactive steering and scripting. Through Python, Synthetic LISA can read and write data files in Flexible Image Transport System (FITS), which is a commonly used astronomical data format.

This program was written by John Armstrong, Jeffrey Edlund, and Michele Vallisneri of Caltech for **NASA's Jet Propulsion Laboratory**.

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41001.

SOFTC: A Software Correlator for VLBI

NASA's Jet Propulsion Laboratory, Pasadena, California

SOFTC is an advanced software implementation of a signal correlator for very-long-baseline interferometry (VLBI) for measuring positions of natural celestial objects and distant spacecraft. Because of increases in processing speeds of general-purpose computers, software VLBI correlators have become viable alternatives to hardware ones. The input to SOFTC consists of digitized samples of raw VLBI-antenna received-signal voltages. Optionally, SOFTC also tracks calibration tones superimposed on the received signals. The outputs of SOFTC are (1) phases and amplitudes as functions of time and frequency for cross-correlated received signals and (2) phases and amplitudes as functions of time, station, and tone number for the calibration tones. SOFTC was created to be as accurate as possible, capable of processing essentially any VLBI data, pass strong debugging tests, have a simple user interface, and have no platform dependencies. SOFTC is written modularly in the C programming language. The great advantage of implementing a correlator in software, in contradistinction to hardware, is that it becomes relatively easy and much less expensive and time-consuming to adapt, modify, improve, and update the correlator.

This program was written by Stephen Lowe 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41072.

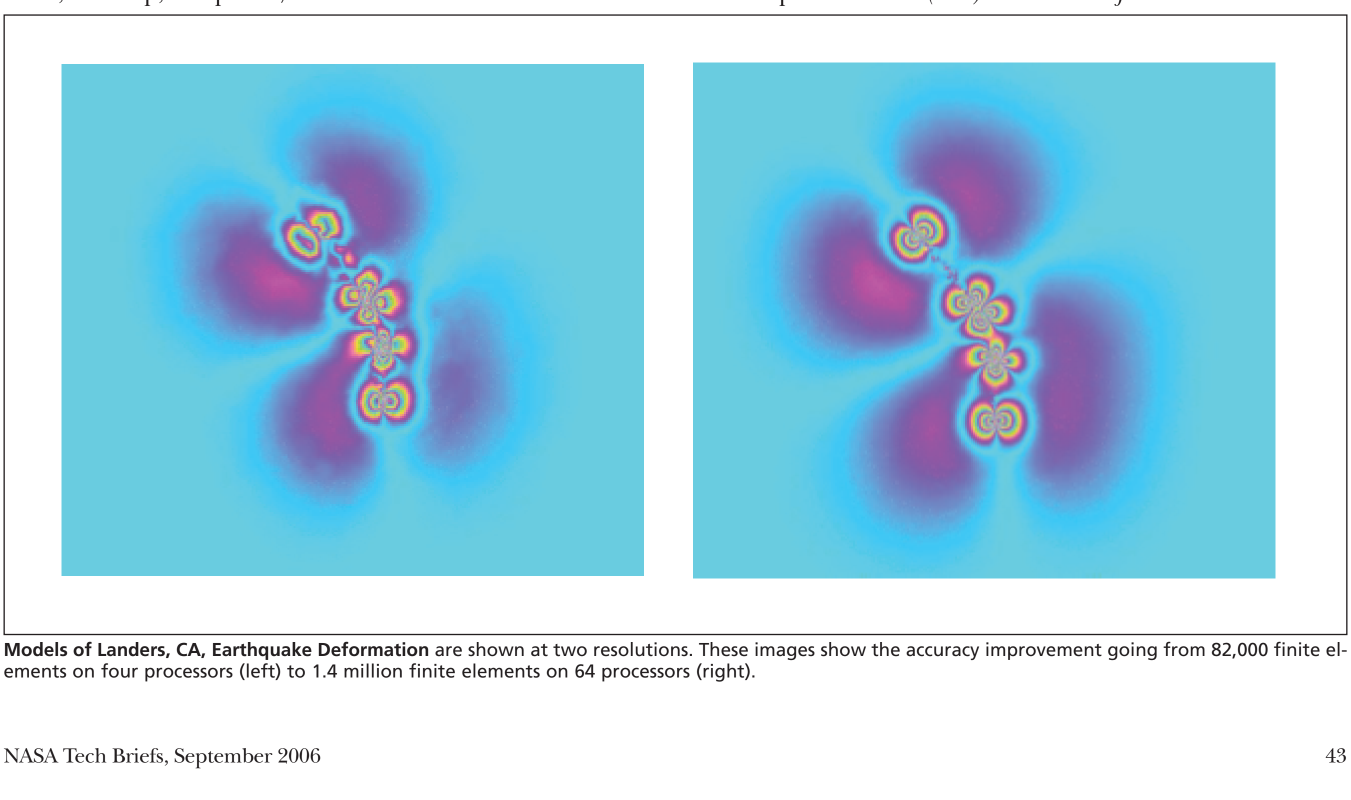
Progress in Computational Simulation of Earthquakes

NASA's Jet Propulsion Laboratory, Pasadena, California

GeoFEST(P) is a computer program written for use in the QuakeSim project, which is devoted to development and improvement of means of computational simulation of earthquakes. GeoFEST(P) models interacting earthquake fault systems from the fault-nucleation to the tectonic scale. The development of GeoFEST(P) has involved coupling of two programs: GeoFEST and the Pyramid Adaptive Mesh Refinement Library. GeoFEST is a message-passing-interface-parallel code that utilizes a finite-element technique to simulate evolution of stress, fault slip, and plastic/elastic deformation in realistic materials like those of faulted regions of the crust of the Earth. The products of such simulations are synthetic observable time-dependent surface deformations on time scales from days to decades. Pyramid Adaptive Mesh Refinement Library is a software library that facilitates the generation of computational meshes for solving physical problems. In an application of GeoFEST(P), a computational grid can be dynamically adapted as stress grows on a fault. Simulations on workstations using a few tens of thousands of stress and displacement finite elements can now be expanded to multiple millions of elements with greater than 98-percent scaled efficiency on over many hundreds of parallel processors (see figure).

This work was done by Andrea Donnellan, Jay Parker, Gregory Lyzenga, Michele Judd, P. Peggy Li, Charles Norton, Edwin Tisdale, and Robert Granat 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41079.



Models of Landers, CA, Earthquake Deformation are shown at two resolutions. These images show the accuracy improvement going from 82,000 finite elements on four processors (left) to 1.4 million finite elements on 64 processors (right).

Database of Properties of Meteors

Marshall Space Flight Center, Alabama

A database of properties of meteors, and software that provides access to the database, are being developed as a contribution to continuing efforts to model the characteristics of meteors with increasing accuracy. Such modeling is necessary for evaluation of the risk of penetration of spacecraft by meteors. For each meteor in the database, the record will include an identification, date and time, radiant properties, ballistic coefficient, radar cross section, size, density, and orbital elements. The property of primary interest in the present case is density, and one of the primary goals in this case is to derive densities of meteors from their atmospheric decelerations. The database and software are expected to be valid anywhere in the solar system. The database will incorporate new data plus results of meteoroid analyses that, heretofore, have not been readily available to the aerospace community. Taken together, the database and software constitute a model that is expected to provide improved estimates of densities and to result in improved risk analyses for interplanetary spacecraft. It is planned to distribute the database and software on a compact disk.

This program was written by Rob Suggs of **Marshall Space Flight Center** *and Coster Anthea of Massachusetts Institute of Technology Lincoln Laboratories. For further information, contact Rob Suggs at rob.suggs@nasa.gov. MFS-32243-1*

Computing Spacecraft Solar-Cell Damage by Charged Particles

Goddard Space Flight Center, Greenbelt, Maryland

General EQFlux is a computer program that converts the measure of the damage done to solar cells in outer space by impingement of electrons and protons having many different kinetic energies into the measure of the damage done by an equivalent fluence of electrons, each having kinetic energy of 1 MeV. Prior to the development of General EQFlux, there was no single computer program offering this capability: For a given type of solar cell, it was necessary to either perform the calculations manually or to use one of three Fortran programs, each of which was applicable to only one type of solar cell. The problem in developing General EQFlux was to rewrite and combine the three programs into a single program that could perform the calculations for three types of solar cells and run in a Windows environment with a Windows graphical user interface. In comparison with the three prior programs, General EQFlux is easier to use.

This program was written by Edward M. Gaddy of **Goddard Space Flight Center**. *For further information, contact the Goddard Innovative Partnerships Office at (301) 286-5810.*
GSC-14791-1

Thermal Model of a Current-Carrying Wire in a Vacuum

NASA's Jet Propulsion Laboratory, Pasadena, California

A computer program implements a thermal model of an insulated wire carrying electric current and surrounded by a vacuum. The model includes the effects of Joule heating, conduction of heat along the wire, and radiation of heat from the outer surface of the insulation on the wire. The model takes account of the temperature dependences of the thermal and electrical properties of the wire, the emissivity of the insulation, and the possibility that not only can temperature vary along the wire but, in addition, the ends of the wire can be thermally grounded at different temperatures. The resulting second-order differential equation for the steady-state temperature as a function of position along the wire is highly nonlinear. The wire is discretized along its length, and the equation is solved numerically by use of an iterative algorithm that utilizes a multidimensional version of the Newton-Raphson method.

This program was written by James Borders 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41067.

Program for Analyzing Flows in a Complex Network

Marshall Space Flight Center, Alabama

Generalized Fluid System Simulation Program (GFSSP) version 4 is a general-purpose computer program for analyzing steady-state and transient flows in a complex fluid network. [GFSSP version 2.01 was reported in a prior issue of *NASA Tech Briefs*.] The program is capable of modeling compressibility, fluid transients (e.g., water hammers), phase changes, mixtures of chemical species, and such externally applied body forces as gravitational and centrifugal ones. A graphical user interface enables the user to interactively develop a simulation of a fluid network consisting of nodes and branches. The user can also run the simulation and view the results in the interface. The system of equations for conservation of mass, energy, chemical species, and momentum is solved numerically by a combination of the Newton-Raphson and successive-substitution methods. The program includes subroutines that compute thermodynamic and thermophysical properties for 12 fluids and is integrated with a commercial program that gives thermodynamic properties of 36 fluids. Eighteen different options are provided for modeling momentum sources or sinks in the branches. Additional capabilities, including new resistance options, new fluids, and nonlinear boundary conditions, can be added by means of subroutines. An audio-visual training CD (compact disk) containing lectures, demonstration of graphical user interface, and tutorial problems is available for learning to use the program.

This program was written by Alok Kumar Majumdar of **Marshall Space Flight Center**. *Further information is contained in a TSP (see page 1).*

This invention is owned by NASA, and a patent application has been filed. For further information, contact Sammy Nabors, MSFC Commercialization Assistance Lead, at sammy.a.nabors@nasa.gov. Refer to MFS-32125-1.

Program Predicts Performance of Optical Parametric Oscillators

Langley Research Center, Hampton, Virginia

A computer program predicts the performances of solid-state lasers that operate at wavelengths from ultraviolet through mid-infrared and that comprise various combinations of stable and unstable resonators, optical parametric oscillators (OPOs), and sum-frequency generators (SFGs), including second-harmonic generators (SHGs). The input to the program describes the signal, idler, and pump beams; the SFG and OPO crystals; and the laser geometry. The program calculates the electric fields of the idler, pump, and output beams at three locations (inside the laser resonator, just outside the input mirror, and just outside the output mirror) as functions of time for the duration of the pump beam. For each beam, the electric field is used to calculate the fluence at the output mirror, plus summary parameters that include the centroid location, the radius of curvature of the wavefront leaving through the output mirror, the location and size of the beam waist, and a quantity known, variously, as a propagation constant or beam-quality factor. The program provides a typical Windows interface for entering data and selecting files. The program can include as many as six plot windows, each containing four graphs.

This program was written by Patricia L. Cross of **Langley Research Center** *and Mark Bowers of Aculight Corporation. Further information is contained in a TSP (see page 1). LAR-16529-1*

Processing TES Level-1B Data

NASA's Jet Propulsion Laboratory, Pasadena, California

TES L1B Subsystem is a computer program that performs several functions for the Tropospheric Emission Spectrometer (TES). The term "L1B" (an abbreviation of "level 1B"), refers to data, specific to the TES, on radiometric calibrated spectral radiances and their corresponding noise equivalent spectral radiances (NESRs), plus ancillary geolocation, quality, and engineering data. The functions performed by TES L1B Subsystem include shear analysis, monitoring of signal levels, detection of ice build-up, and phase correction and radiometric and spectral calibration of TES target data. Also, the program computes NESRs for target spectra, writes scientific TES level-1B data to hierarchical-data-format (HDF) files for public distribution, computes brightness temperatures, and quantifies interpixel signal variability for the purpose of first-order cloud and heterogeneous land screening by the level-2 software summarized in the immediately following article. This program uses an in-house-developed algorithm, called "NUSRT," to correct instrument line-shape factors.

This program was written by Richard C. De Baca, Edwin Sarkissian, Mariyetta Madatyan, Douglas Shepard, Scott Gluck, Mark Apolinski, James McDuffie, and Dennis Tremblay 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-35218.

Automated Camera Calibration

NASA's Jet Propulsion Laboratory, Pasadena, California

Automated Camera Calibration (ACAL) is a computer program that automates the generation of calibration data for camera models used in machine vision systems. Machine vision camera models describe the mapping between points in three-dimensional (3D) space in front of the camera and the corresponding points in two-dimensional (2D) space in the camera's image. Calibrating a camera model requires a set of calibration data containing known 3D-to-2D point correspondences for the given camera system. Generating calibration data typically involves taking images of a calibration target where the 3D locations of the target's fiducial marks are known, and then measuring the 2D locations of the fiducial marks in the images. ACAL automates the analysis of calibration target images and greatly speeds the overall calibration process. ACAL consists of three modules:

1. ACALDOTS — the primary module — takes calibration target images, locates and measures the 2D locations of the target's fiducial marks and then synthesizes their corresponding 3D locations based on knowledge of the calibration target's geometry and its 3D location. ACALDOTS handles uneven lighting, large-scale variations due to range differences, and barrel distortion effects of the type found in wide-angle lenses. It understands both planar and corner-cube (i.e., 3D) calibration target geometries.
2. ACALINFO takes the calibration data produced by ACALDOTS and estimates an initial 3D position and orientation (i.e., camera pose) for the camera to seed the estimation of the remaining camera model parameters.
3. ACALFIX takes the original calibration data and the camera model produced from it and generates a refined set of calibration data by removing localization errors in the 2D fiducial mark positions introduced by perspective foreshortening caused by the calibration target's orientation and geometry.

The automation in ACAL is robust enough that under even extreme image conditions, the required input from the user averages to no more than about one mouse click per target fixture.

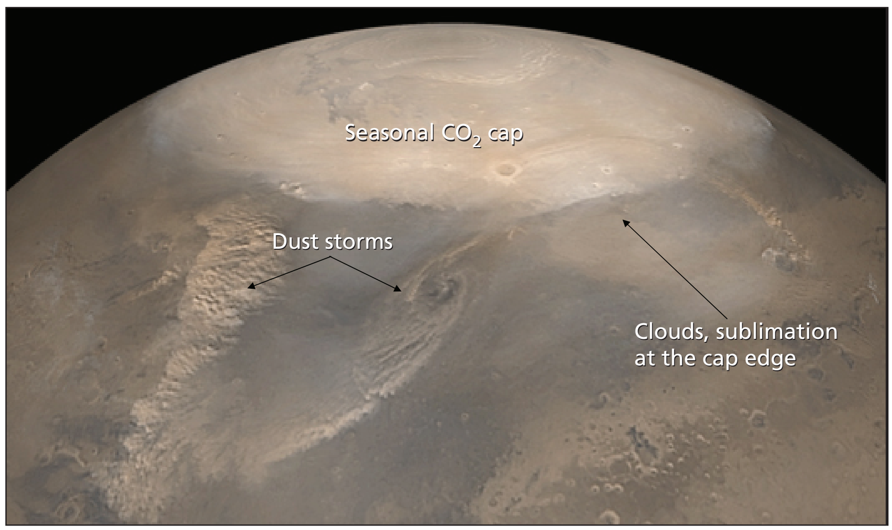
This program was written by Siqi Chen, Yang Cheng, and Reg Willson of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41312.

Tracking the Martian CO_2 Polar Ice Caps in Infrared Images

NASA's Jet Propulsion Laboratory, Pasadena, California

Researchers at NASA's Jet Propulsion Laboratory have developed a method for automatically tracking the polar caps on Mars as they advance and recede each year (see figure). The seasonal Mars polar caps are composed mainly of CO_2 ice and are therefore cold enough to stand out clearly in infrared data collected by the Thermal Emission Imaging System (THEMIS) onboard the Mars Odyssey spacecraft. The Bimodal Image Temperature (BIT) histogram analysis algorithm analyzes raw, uncalibrated data to identify images that contain both "cold" ("polar cap") and "warm" ("not polar cap") pixels. The algorithm dynamically identifies the temperature that separates these two regions. This flexibility is critical, because in the absence of any calibration, the threshold temperature can vary significantly from image to image. Using the identified threshold, the algorithm classifies each pixel in the image as "polar cap" or "not polar cap," then identifies the image row that contains the spatial transition from "polar cap" to "not polar cap." While this method is useful for analyzing data that has already been returned by THEMIS, it has even more significance with respect to data that has not yet been collected. Instead of seeking the polar cap only in specific, targeted images, the simplicity and efficiency of this method makes it feasible for direct, onboard use. That is, THEMIS could continuously monitor its observations for any detections of the polar-cap edge, producing detections over a wide range of spatial and temporal conditions. This effort can greatly contribute to our understanding of long-term climatic change on Mars.



Recession of the Seasonal CO_2 Cap is shown for Northern Martian Spring.

This work was done by Kiri L. Wagstaff, Rebecca Castano, and Steve Chien 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41732.

Processing TES Level-2 Data

NASA's Jet Propulsion Laboratory, Pasadena, California

TES Level 2 Subsystem is a set of computer programs that performs functions complementary to those of the program summarized in the immediately preceding article. TES Level-2 data pertain to retrieved species (or temperature) profiles, and errors thereof. Geolocation, quality, and other data (e.g., surface characteristics for nadir observations) are also included. The subsystem processes gridded meteorological information and extracts parameters that can be interpolated to the appropriate latitude, longitude, and pressure level based on the date and time. Radiances are simulated using the aforementioned meteorological information for initial guesses, and spectroscopic-parameter tables are generated. At each step of the retrieval, a nonlinear-least-squares-solving routine is run over multiple iterations, retrieving a subset of atmospheric constituents, and error analysis is performed. Scientific TES Level-2 data products are written in a format known as Hierarchical Data Format Earth Observing System 5 (HDF-EOS 5) for public distribution.

This software was written by Sassaneh Poosti, Sirvard Akopyan, Regina Sakurai, Hyejung Yun, Pranjit Saha, Irina Strickland, Kevin Croft, Weldon Smith, Rodney Hoffman, John Koffend, Gerard Benenyan, Hari Nair, Edwin Sarkissian, James McDuffie, Ruth Monarrez, David Ho, Benny Chan, and Michael Lampel 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-35212.

SmaggIce Version 1.8

John H. Glenn Research Center, Cleveland, Ohio

SmaggIce version 1.8 is a set of software tools for geometrical modeling of, and generation of grids that conform to, both clean and iced airfoils. A prior version (SmaggIce 1.2) was described in "Preparing and Analyzing Iced Airfoils" (LEW-17399), *NASA Tech Briefs*, Vol. 28, No. 8 (August 2004), page 32. Ice shapes, especially those that include rough surfaces, pose difficulty in generating high-quality grids that are essential for predicting airflows by use of computational fluid dynamics. SmaggIce version 1.8 contains software tools needed to overcome this difficulty. For a given airfoil, it allows the user to define the flow domain, decompose the domain into blocks, generate grids, merge gridded blocks, and control the density and smoothness of each grid. Among the unique features of version 1.8 is a thin C-shaped block, called a "viscous sublayer block," which is wrapped around an iced airfoil and its wake line and serves as a means to generate highly controlled grids near the rough ice surface. Users can modify block boundary shapes using control points of non-uniform rational B-spline (NURBS) curves. Concave ice regions can be smoothed during geometrical modeling or creation of the viscous sublayer block.

This work was done by Mary B. Vickerman, Marivell Baez, Herbert W. Schilling, Barbara J. Wilson, Donald C. Braun, Anthony W. Hackenberg, James A. Pennline, Rula M. Coroneos, and Yung K. Choo of **Glenn Research Center**. *Further information is contained in a TSP (see page 1).*

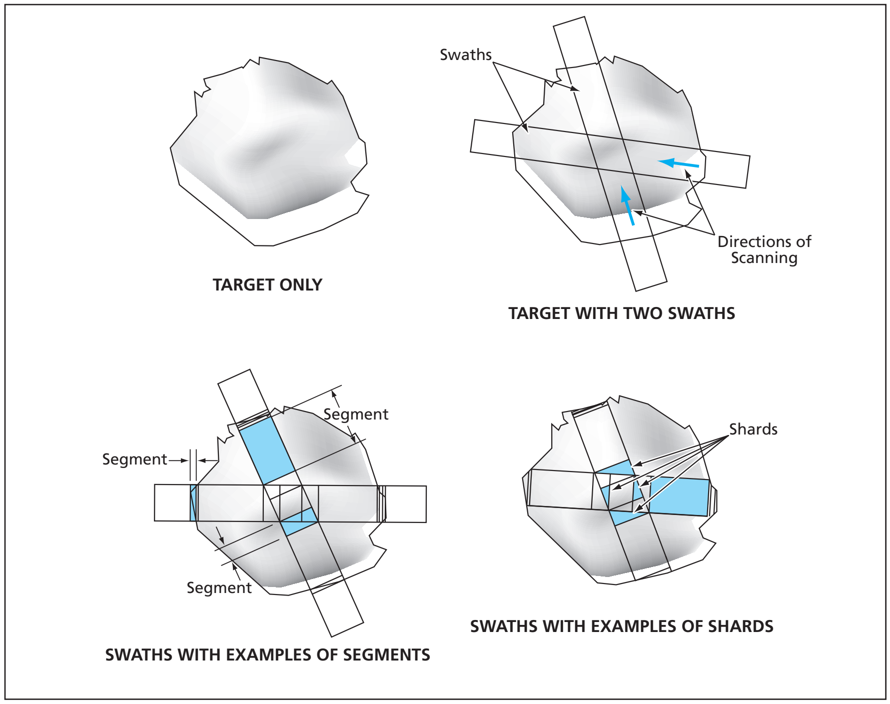
Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17846-1.

Solving the Swath Segment Selection Problem

Several techniques for solving the problem have been tested and compared.

NASA's Jet Propulsion Laboratory, Pasadena, California

Several artificial-intelligence search techniques have been tested as means of solving the swath segment selection problem (SSSP) — a real-world problem that is not only of interest in its own right, but is also useful as a test bed for search techniques in general. In simplest terms, the SSSP is the problem of scheduling the observation times of an airborne or spaceborne synthetic-aperture radar (SAR) system to effect the maximum coverage of a specified area (denoted the target), given a schedule of downlinks (opportunities for radio transmission of SAR scan data to a ground station), given the limit on the quantity of SAR scan data that can be stored in an onboard memory between downlink opportunities, and given the limit on the achievable downlink data rate. The SSSP is NP complete (short for "nondeterministic polynomial time complete" — characteristic of a class of intractable problems that can be solved only by use of computers capable of making guesses and then checking the guesses in polynomial time).



Target Area Is Divided into swaths, segments, and shards for the purpose of mathematical modeling in the SSSP.

For the purpose of mathematical modeling for the SSSP, a target is approximated as being planar and is subdivided in a pattern of swaths, segments, and shards (see figure). A swath is defined as area, usually rectangular, that can be scanned during a given interval of time. Segments are portions of swaths (also usually rectangular) defined by intersections of swath and target boundaries. Shards — so named because they resemble pieces of broken glass — are polygonal areas that are derived from segments and that represent pieces of target area for which data can be gathered and downlinked.

The search techniques tested as means of solving the SSSP include the following:

- *Forward Dispatch*: Segments are added in temporal order until the system becomes oversubscribed. When the addition of a segment results in an oversubscription, the computation is rolled back to remove that segment, then the computation resumes without that segment. In comparison with the other techniques, this technique requires the least amount of computation time but yields solutions of poor quality.
- *Mixed Integer Programming*: Mixed integer programming is a hybrid of integer and linear programming. It applies to a formulation of the SSSP in which the relationships among variables and constraints are expressed by matrix-vector equations and inequalities. In linear programming, the variables can have continuous values and one seeks a vector of such variables that minimizes or maximizes an objective function. An integer program includes the additional constraint that the variables must all have integer values. Integer programming gives optimal solutions, but requires the greatest amount of computation time, even when one accepts suboptimal solutions. In mixed integer programming, some variables are integers and some are continuous.
- *Network Flow Relaxation With Depth-First Branch and Bound*: One constructs a network flow graph — a directed, edge-labeled graph that represents the flow of information through the problem. This graph is used in conjunction with depth-first branch-and-bound (DFBnB) algorithm. This technique provides the same information as does integer, mixed integer, or linear programming while requiring less computation time.

The results of tests performed thus far have led to the conclusion that for best performance, one should start with forward dispatch followed immediately by DFBnB.

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

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40454.

The Spatial Standard Observer

Degrees of visibility and discriminability of targets in images can be estimated.

Ames Research Center, Moffett Field, California

The spatial standard observer is a computational model that provides a measure of the visibility of a target in a uniform background image or of the visual discriminability of two images. Standard observers have long been used in science and industry to quantify the discriminability of colors. Color standard observers address the spectral characteristics of visual stimuli, while the spatial standard observer (SSO), as its name indicates, addresses spatial characteristics.

The **SSO Was Applied to These Two Images** of targets viewed from a UAV. The left image contains a target calculated to have a visibility of 4.25 JND; the right image contains a similar target that has been reduced in contrast to have a visibility of 1 JND.

The SSO is based on a model of human vision. The SSO was developed in a process that included evaluation of a number of earlier mathematical models that address optical, physiological, and psychophysical aspects of spatial characteristics of human visual perception. Elements of the prior models are incorporated into the SSO, which is formulated as a compromise between accuracy and simplicity. The SSO operates on a digitized monochrome still image or on a pair of such images. The SSO consists of three submodels that operate sequentially on the input image(s):

1. A contrast model, which converts an input monochrome image to a luminance contrast image, wherein luminance values are expressed as excursions from, and normalized to, a mean;
2. A contrast-sensitivity-filter model that includes an oblique-effect filter (which accounts for the decline in contrast sensitivity at oblique viewing angles); and
3. A spatial summation model, in which responses are spatially pooled by raising each pixel to the power beta, adding the results, and raising the sum to the $1/\beta$ power. In this model, β=2.9 was found to be a suitable value.

The net effect of the SSO is to compute a numerical measure of the perceptual strength of the single image, or of the visible difference (denoted the perceptual distance) between two images. The unit of a measure used in the SSO is the just noticeable difference (JND), which is a standard measure of perceptual discriminability. A target that is just visible has a measure of 1 JND.

The SSO was devised to satisfy an increasing need for a rapid, objective means of estimating degrees of visibility and discriminability of visual elements in scenes observed, not only by humans, but also by robotic vision systems, under a variety of circumstances. Examples of potential applications of the SSO include evaluating vision from unpiloted aerial vehicles (UAVs) [see figure]; predicting visibility of UAVs from other aircraft; estimating visibility, from a control tower, of aircraft on runways; measuring visibility, from a distance, of damage on aircraft and on a space shuttle; evaluation of legibility of text, icons, or other symbols; specification of resolution of a camera or a display device; inspection of display devices during manufacturing; estimating the quality of compressed digital video imagery; and predicting the outcomes of corrective laser eye surgery.

This work was done by Andrew B. Watson and Albert J. Ahumada, Jr., of **Ames Research Center**.

This invention is owned by NASA and a patent application has been filed. Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954.Refer to ARC-14569-1.

Less-Complex Method of Classifying MPSK

Nearly optimal performance can be obtained with less computation.

NASA's Jet Propulsion Laboratory, Pasadena, California

An alternative to an optimal method of automated classification of signals modulated with *M*-ary phase-shift-keying (*M*-ary PSK or MPSK) has been derived. The alternative method is approximate, but it offers nearly optimal performance and entails much less complexity, which translates to much less computation time.

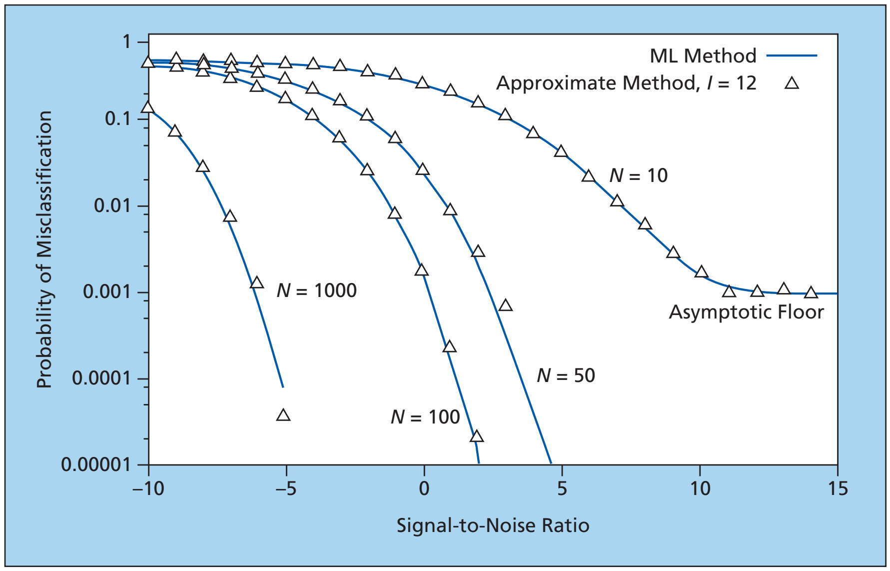
Modulation classification is becoming increasingly important in radio-communication systems that utilize multiple data modulation schemes and include software-defined or software-controlled receivers. Such a receiver may "know" little *a priori* about an incoming signal but may be required to correctly classify its data rate, modulation type, and forward error-correction code before properly configuring itself to acquire and track the symbol timing, carrier frequency, and phase, and ultimately produce decoded bits. Modulation classification has long been an important component of military interception of initially unknown radio signals transmitted by adversaries. Modulation classification may also be useful for enabling cellular telephones to automatically recognize different signal types and configure themselves accordingly.

The concept of modulation classification as outlined in the preceding paragraph is quite general. However, at the present early stage of development, and for the purpose of describing the present alternative method, the term "modulation classification" or simply "classification" signifies, more specifically, a distinction between M-ary and M'-ary PSK, where M and M' represent two different integer multiples of 2.

Both the prior optimal method and the present alternative method require the acquisition of magnitude and phase values of a number (N) of consecutive baseband samples of the incoming signal + noise. The prior optimal method is based on a maximum-likelihood (ML) classification rule that requires a calculation of likelihood functions for the M and M' hypotheses: Each likelihood function is an integral, over a full cycle of carrier phase, of a complicated sum of functions of the baseband sample values, the carrier phase, the carrier-signal and noise magnitudes, and M or M'. Then the likelihood ratio, defined as the ratio between the likelihood functions, is computed, leading to the choice of whichever hypothesis — M or M' — is more likely.

In the alternative method, the integral in each likelihood function is approximated by a sum over values of the integrand sampled at a number, I, of equally spaced values of carrier phase. Used in this way, I is a parameter that can be adjusted to trade computational complexity against the probability of misclassification. In the limit as $I \rightarrow \infty$, one obtains the integral form of the likelihood function and thus recovers the ML classification.

The present approximate method has been tested in comparison with the ML method by means of computational simulations. The results of the simulations have shown that the performance (as quantified by probability of misclassification) of the approximate method is nearly indistinguishable from that of the ML method (see figure).



Performances of the ML and Approximate Methods were computed in simulations for a case of noncoherent reception of signals that had equal probability of being binary PSK or quaternary PSK.

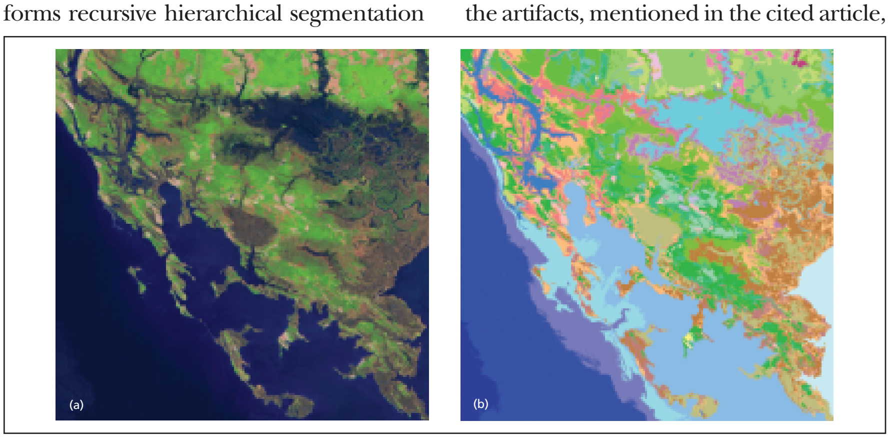
This work was done by Jon Hamkins of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1). NPO-40965*

Improvement in Recursive Hierarchical Segmentation of Data

Goddard Space Flight Center, Greenbelt, Maryland

A further modification has been made in the algorithm and implementing software reported in "Modified Recursive Hierarchical Segmentation of Data" (GSC-14681-1), *NASA Tech Briefs*, Vol. 30, No. 6 (June 2006), page 51. That software performs recursive hierarchical segmentation of data having spatial characteristics (e.g., spectral-image data). The output of a prior version of the software contained artifacts, including spurious segmentation-image regions bounded by processing-window edges. The modification for suppressing the artifacts, mentioned in the cited article, was addition of a subroutine that analyzes data in the vicinities of seams to find pairs of regions that tend to lie adjacent to each other on opposite sides of the seams. Within each such pair, pixels in one region that are more similar to pixels in the other region are reassigned to the other region.

The present modification provides for a parameter ranging from 0 to 1 for controlling the relative priority of merges between spatially adjacent and spatially non-adjacent regions. At 1, spatially-adjacent-/spatially-non-adjacent-region merges have equal priority. At 0, only spatially-adjacent-region merges (no spectral clustering) are allowed. Between 0 and 1, spatially-adjacent-region merges have priority over spatially-non-adjacent ones.



A Segmentation of the Landsat ETM+ Image displayed on the left is shown on the right. The new approach eliminates processing artifacts.

This program was written by James C. Tilton of **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*
GSC-14994-1

Using Heaps in Recursive Hierarchical Segmentation of Data

Goddard Space Flight Center, Greenbelt, Maryland

A modification to increase processing speed has been made in the algorithm and implementing software reported in "Modified Recursive Hierarchical Segmentation of Data" (GSC-14681-1), *NASA Tech Briefs*, Vol. 30, No. 6 (June 2006), page 51. That software performs recursive hierarchical segmentation of data having spatial characteristics (e.g., spectral-image data). The segmentation process includes an iterative subprocess, in each iteration of which it is necessary to determine a best pair of regions to merge [merges being justified by one or more measure(s) similarity of pixels in the regions]. In the previously reported version of the algorithm and software, the choice of a best pair of regions to merge involved the use of a fully sorted list of regions. That version was computationally inefficient because a fully sorted list is not needed: what is needed is only the identity of the pair of regions characterized by the smallest measure of dissimilarity. The present modification replaces the use of a fully sorted list with the use of data heaps, which are computationally more efficient for performing the required comparisons among dissimilarity measures. The modification includes the incorporation of standard and modified functions for creating and updating data heaps.

This program was written by James C. Tilton of **Goddard Space Flight Center**. *Further information is contained in a TSP (see page 1).*
GSC-14995-1

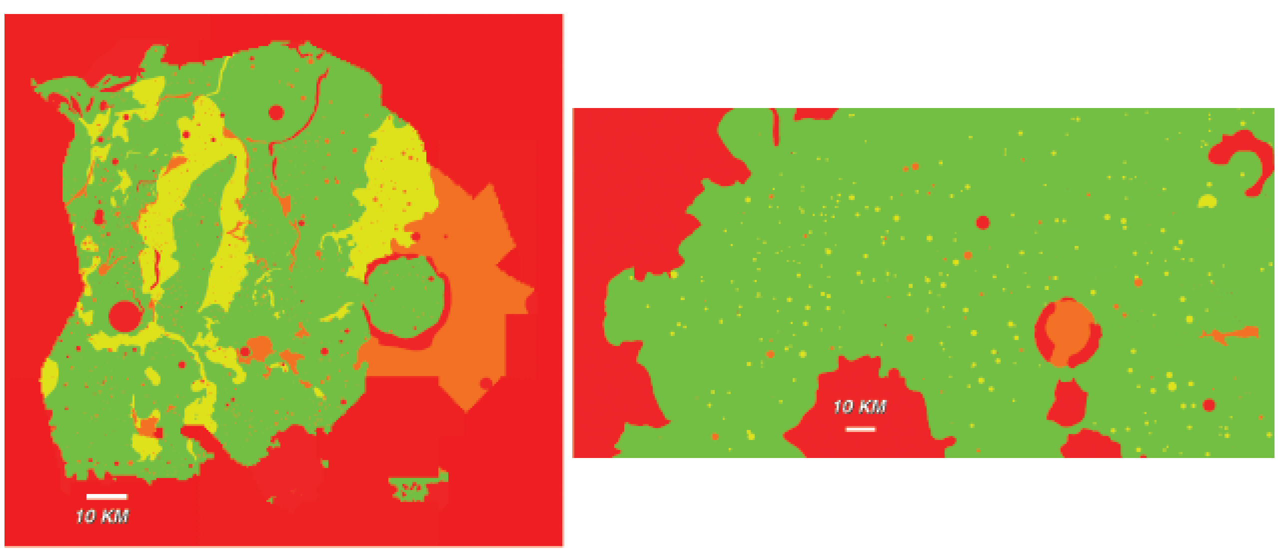
Tool for Statistical Analysis and Display of Landing Sites

NASA's Jet Propulsion Laboratory, Pasadena, California

MarsLS is a software tool for analyzing statistical dispersion of spacecraft-landing sites and displaying the results of its analyses. Originally intended for the Mars Explorer Rover (MER) mission, MarsLS is also applicable to landing sites on Earth and non-MER sites on Mars. MarsLS is a collection of interdependent MATLAB scripts that utilize the MATLAB graphical-user-interface software environment to display landing-site data (see figure) on calibrated image-maps of the Martian or other terrain. The landing-site data comprise latitude/longitude pairs generated by Monte Carlo runs of other computer programs that simulate entry, descent, and landing. Using these data, MarsLS can compute a landing-site ellipse — a standard means of depicting the area within which the spacecraft can be expected to land with a given probability. MarsLS incorporates several features for the user's convenience, including capabilities for drawing lines and ellipses, overlaying kilometer or latitude/longitude grids, drawing and/or specifying lines and/or points, entering notes, defining and/or displaying polygons to indicate hazards or areas of interest, and evaluating hazardous and/or scientifically interesting areas. As part of such an evaluation, MarsLS can compute the probability of landing in a specified polygonal area.

This program was written by Geoffrey Wawrzyniak, Brian Kennedy, Philip Knocke, and John Michel 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-35239.

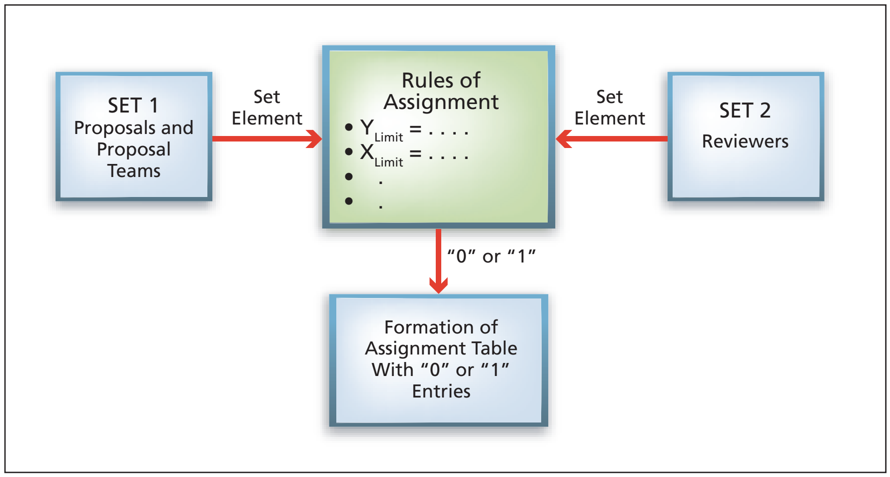


Martian Landing Site Hazard Maps are shown for Spirit (Gusev) and Opportunity (Meridiani). Here, red = not survivable; green = plains; orange = eroded craters; and yellow = subdued craters.

Automated Assignment of Proposals to Reviewers

NASA's Jet Propulsion Laboratory, Pasadena, California

A computer program automates the process of selecting unbiased peer reviewers of research proposals submitted to NASA. Heretofore, such selection has been performed by manual searching of two large databases subject to a set of assignment rules. One database lists proposals and proposers; the other database lists potential reviewers. The manual search takes an average of several weeks per proposal. In contrast, the present software can perform the selection in seconds. The program begins by selecting one entry from each database, then applying the assignment rules to this pair of entries. If and only if all the assignment rules are satisfied, the chosen reviewer is assigned to the chosen proposal. The assignment rules enforced by the program are (1) a maximum allowable number of proposals assigned to a single reviewer; (2) a maximum allowable number of reviewers assigned to a single proposal; (3) if the proposing team includes a member affiliated with an industry, then the reviewer must not be affiliated with any industry; and (4) the reviewer must not be a member of the proposing team or affiliated with the same institution as that of a member of the proposing team.



The **Assignment Process** begins with selection of an element from Set 1 and from Set 2 and follows a set of rules to avoid biases and other problems in proposal reviews.

This program was written Faiza Lansing and Anil Kantak 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40902.

Array-Pattern-Match Compiler for Opportunistic Data Analysis

NASA's Jet Propulsion Laboratory, Pasadena, California

A computer program has been written to facilitate real-time sifting of scientific data as they are acquired to find data patterns deemed to warrant further analysis. The patterns in question are of a type denoted array patterns, which are specified by nested parenthetical expressions. [One example of an array pattern is ((>3) 0 (≠1)): this pattern matches a vector of at least three elements, the first of which exceeds 3, the second of which is 0, and the third of which does not equal 1.] This program accepts a high-level description of a static array pattern and compiles a highly optimal and compact other program to determine whether any given instance of any data array matches that pattern. The compiler implemented by this program is independent of the target language, so that as new languages are used to write code that processes scientific data, they can easily be adapted to this compiler. This program runs on a variety of different computing platforms. It must be run in conjunction with any one of a number of Lisp compilers that are available commercially or as shareware.

This program was written by Mark James 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42096.

Pre-Processor for Compression of Multispectral Image Data

NASA's Jet Propulsion Laboratory, Pasadena, California

A computer program that preprocesses multispectral image data has been developed to provide the Mars Exploration Rover (MER) mission with a means of exploiting the additional correlation present in such data without appreciably increasing the complexity of compressing the data. When used in conjunction with ICER, a previously developed image-data-compression program, this program enables improved compression of multispectral images, compared to that achievable by use of ICER alone. As such, it is a straightforward means of achieving much of the gain possible from exploiting spectral correlation. This preprocessor software accommodates up to seven images that are different spectral bands of the same scene. The software performs an approximate discrete cosine transform (DCT) pixelwise across the spectral bands. The software is written for speed; in particular the DCT operation performs only integer operations (producing integer output) and uses multiplications sparingly. Separate code is used for each possible number of spectral bands, including numbers for which fast DCT functions are not normally implemented. The DCT output is scaled so that, if the original images have a bit depth of at most 12, the transformed images are guaranteed to have a dynamic range appropriate for compression by the ICER software on the MER rovers. The resulting transformed bands are compressed individually by ICER. To reconstruct the images, the transformed images are first decompressed by use of the decompressor for ICER, then the resulting reconstructed images are passed to an inverse-DCT subprogram, which reconstructs the various spectral bands.

This work was done by Matthew Klimesh and Aaron Kiely 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40835.

Compressing Image Data While Limiting the Effects of Data Losses

NASA's Jet Propulsion Laboratory, Pasadena, California

ICER is computer software that can perform both lossless and lossy compression and decompression of gray-scale-image data using discrete wavelet transforms. Designed for primary use in transmitting scientific image data from distant spacecraft to Earth, ICER incorporates an error-containment scheme that limits the adverse effects of loss of data and is well suited to the data packets transmitted by deep-space probes. The error-containment scheme includes utilization of the algorithm described in "Partitioning a Gridded Rectangle Into Smaller Rectangles" (NPO-30479), *NASA Tech Briefs*, Vol. 28, No. 7 (July 2004), page 56. ICER has performed well in onboard compression of thousands of images transmitted from the Mars Exploration Rovers.

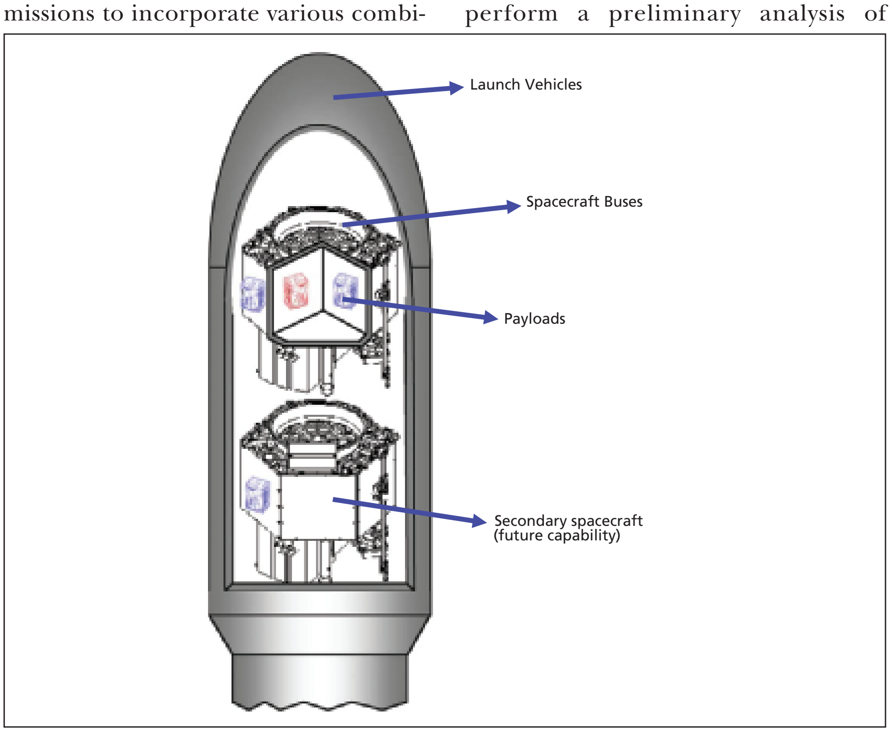
This program was written by Aaron Kiely and Matthew Klimesh of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40982.

Flight Operations Analysis Tool

NASA's Jet Propulsion Laboratory, Pasadena, California

Flight Operations Analysis Tool (FLOAT) is a computer program that partly automates the process of assessing the benefits of planning spacecraft missions to incorporate various combinations of launch vehicles and payloads (see figure). Designed primarily for use by an experienced systems engineer, FLOAT makes it possible to perform a preliminary analysis of trade-offs and costs of a proposed mission in days, whereas previously, such an analysis typically lasted months. FLOAT surveys a variety of prior missions by querying data from authoritative NASA sources pertaining to 20 to 30 mission and interface parameters that define space missions. FLOAT provides automated, flexible means for comparing the parameters to determine compatibility or the lack thereof among payloads, spacecraft, and launch vehicles, and for displaying the results of such comparisons. Sparseness, typical of the data available for analysis, does not confound this software. FLOAT effects an iterative process that identifies modifications of parameters that could render compatible an otherwise incompatible mission set.



The **Database Overview** shows current and future capabilities.

This program was written by Robert Easter, Linda Herrell, Richard Pomphrey, James Chase, Julie Wertz Chen, Jeffrey Smith, and Rebecca Carter 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42306.

Improvement in Visual Target Tracking for a Mobile Robot

NASA's Jet Propulsion Laboratory, Pasadena, California

In an improvement of the visual-target-tracking software used aboard a mobile robot (rover) of the type used to explore the Martian surface, an affine-matching algorithm has been replaced by a combination of a normalized-cross-correlation (NCC) algorithm and a template-image-magnification algorithm. Although neither NCC nor template-image magnification is new, the use of both of them to increase the degree of reliability with which features can be matched is new. In operation, a template image of a target is obtained from a previous rover position, then the magnification of the template image is based on the estimated change in the target distance from the previous rover position to the current rover position (see figure). For this purpose, the target distance at the previous rover position is determined by stereoscopy, while the target distance at the current rover position is calculated from an estimate of the current pose of the rover. The template image is then magnified by an amount corresponding to the estimated target distance to obtain a best template image to match with the image acquired at the current rover position.

This program was written by Won Kim, Adnan Ansar, and Richard Madison 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42682.

Turn-in-Place Experiments show beginning image (left) and end image (right) after 80° rover rotation. As the rover turns, the mast camera turns in the opposite direction to point to the target.

Software for Simulating Air Traffic

Ames Research Center, Moffett Field, California

Future Air Traffic Management Concepts Evaluation Tool (FACET) is a system of software for performing computational simulations for evaluating advanced concepts of advanced air-traffic management. FACET includes a program that generates a graphical user interface plus programs and databases that implement computational models of weather, airspace, airports, navigation aids, aircraft performance, and aircraft trajectories. Examples of concepts studied by use of FACET include aircraft self-separation for free flight; prediction of air-traffic-controller workload; decision support for direct routing; integration of spacecraft-launch operations into the U.S. national airspace system; and traffic-flow-management using rerouting, metering, and ground delays. Aircraft can be modeled as flying along either flight-plan routes or great-circle routes as they climb, cruise, and descend according to their individual performance models. The FACET software is modular and is written in the Java and C programming languages. The architecture of FACET strikes a balance between flexibility and fidelity; as a consequence, FACET can be used to model system-wide airspace operations over the contiguous U.S., involving as many as 10,000 aircraft, all on a single desktop or laptop computer running any of a variety of operating systems. Two notable applications of FACET include: (1) reroute conformance monitoring algorithms that have been implemented in one of the Federal Aviation Administration's nationally deployed, real-time, operational systems; and (2) the licensing and integration of FACET with the commercially available Flight Explorer, which is an Internet-based, real-time flight-tracking system.

This program was written by Banavar Sridhar, Karl Bilimoria, and Shon Grabbe of **Ames Research Center** *and Gano Chatterji, Kapil Sheth, and Daniel Mulfinger of Raytheon Co. Further information is contained in a TSP (see page 1).*

This invention is owned by NASA and a patent application has been filed. Inquiries concerning rights for the commercial use of this invention should be addressed to the Ames Technology Partnerships Division at (650) 604-2954. Refer to ARC-14653-1.

Automated Vectorization of Decision-Based Algorithms

NASA's Jet Propulsion Laboratory, Pasadena, California

Virtually all existing vectorization algorithms are designed to only analyze the numeric properties of an algorithm and distribute those elements across multiple processors. This advances the state of the practice because it is the only known system, at the time of this reporting, that takes high-level statements and analyzes them for their decision properties and converts them to a form that allows them to automatically be executed in parallel.

The software takes a high-level source program that describes a complex decision-based condition and rewrites it as a disjunctive set of component Boolean relations that can then be executed in parallel. This is important because parallel architectures are becoming more commonplace in conventional systems and they have always been present in NASA flight systems. This technology allows one to take existing condition-based code and automatically vectorize it so it naturally decomposes across parallel architectures.

This program was written by Mark James 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42524.

Grayscale Optical Correlator Workbench

NASA's Jet Propulsion Laboratory, Pasadena, California

Grayscale Optical Correlator Workbench (GOCWB) is a computer program for use in automatic target recognition (ATR). GOCWB performs ATR with an accurate simulation of a hardware grayscale optical correlator (GOC). This simulation is performed to test filters that are created in GOCWB. Thus, GOCWB can be used as a stand-alone ATR software tool or in combination with GOC hardware for building (target training), testing, and optimization of filters. The software is divided into three main parts, denoted filter, testing, and training. The training part is used for assembling training images as input to a filter. The filter part is used for combining training images into a filter and optimizing that filter. The testing part is used for testing new filters and for general simulation of GOC output. The current version of GOCWB relies on the mathematical software tools from MATLAB binaries for performing matrix operations and fast Fourier transforms. Optimization of filters is based on an algorithm, known as OT-MACH, in which variables specified by the user are parameterized and the best filter is selected on the basis of an average result for correct identification of targets in multiple test images.

This program was written by Jay Hanan, Hanying Zhou, and Tien-Hsin Chao 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41021.

"One-Stop Shopping" for Ocean Remote-Sensing and Model Data

NASA's Jet Propulsion Laboratory, Pasadena, California

OurOcean Portal 2.0 (http://ourocean.jpl.nasa.gov) is a software system designed to enable users to easily gain access to ocean observation data, both remote-sensing and *in-situ*, configure and run an Ocean Model with observation data assimilated on a remote computer, and visualize both the observation data and the model outputs. At present, the observation data and models focus on the California coastal regions and Prince William Sound in Alaska. This system can be used to perform both real-time and retrospective analyses of remote-sensing data and model outputs. OurOcean Portal 2.0 incorporates state-of-the-art information technologies (IT) such as MySQL database, Java Web Server (Apache/Tomcat), Live Access Server (LAS), interactive graphics with Java Applet at the Client site and MatLab/GMT at the server site, and distributed computing. OurOcean currently serves over 20 real-time or historical ocean data products. The data are served in pre-generated plots or their native data format. For some of the datasets, users can choose different plotting parameters and produce customized graphics. OurOcean also serves 3D Ocean Model outputs generated by ROMS (Regional Ocean Model System) using LAS. The Live Access Server (LAS) software, developed by the Pacific Marine Environmental Laboratory (PMEL) of the National Oceanic and Atmospheric Administration (NOAA), is a configurable Web-server program designed to provide flexible access to geo-referenced scientific data. The model output can be views as plots in horizontal slices, depth profiles or time sequences, or can be downloaded as raw data in different data formats, such as NetCDF, ASCII, Binary, etc. The interactive visualization is provided by graphic software, Ferret, also developed by PMEL. In addition, OurOcean allows users with minimal computing resources to configure and run an Ocean Model with data assimilation on a remote computer. Users may select the forcing input, the data to be assimilated, the simulation period, and the output variables and submit the model to run on a backend parallel computer. When the run is complete, the output will be added to the LAS server for user to retrieve and examine the results.

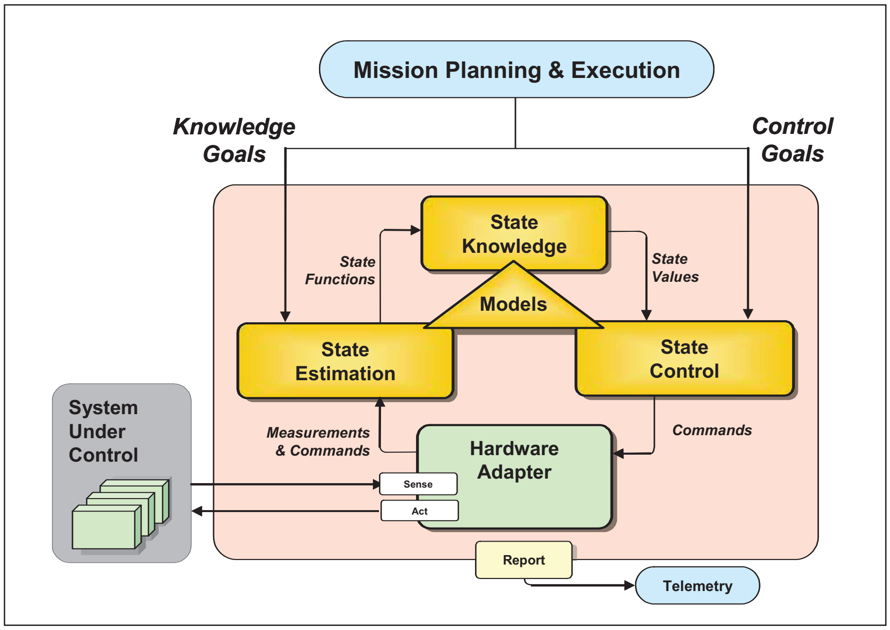
This program was written by P. Peggy Li, Quoc Vu, and Yi Chao of Caltech, and Zhijin Li and Jei-Kook Choi of Raytheon for **NASA's Jet Propulsion Laboratory**.

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41761.

State Analysis Database Tool

NASA's Jet Propulsion Laboratory, Pasadena, California

The State Analysis Database Tool software establishes a productive environment for collaboration among software and system engineers engaged in the development of complex interacting systems. The tool embodies *State Analysis*, a model-based system engineering methodology founded on a state-based control architecture (see figure). A state represents a momentary condition of an evolving system, and a model may describe how a state evolves and is affected by other states. The State Analysis methodology is a process for capturing system and software requirements in the form of explicit models and states, and defining goal-based operational plans consistent with the models. Requirements, models, and operational concerns have traditionally been documented in a variety of system engineering artifacts that address different aspects of a mission's lifecycle. In State Analysis, requirements, models, and operations information are State Analysis artifacts that are consistent and stored in a State Analysis Database. The tool includes a back-end database, a multi-platform front-end client, and Web-based administrative functions. The tool is structured to prompt an engineer to follow the State Analysis methodology, to encourage state discovery and model description, and to make software requirements and operations plans consistent with model descriptions.



The **State-Based Control Architecture** is the foundation of the present software.

This program was written by Robert Rasmussen and Matthew Bennett of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42869.

Generating CAHV and CAHVOR Images With Shadows in ROAMS

NASA's Jet Propulsion Laboratory, Pasadena, California

Part of the Rover Analysis, Modeling and Simulation (ROAMS) software that synthesizes images of terrain has been augmented to make the images more realistic. [ROAMS was described in "Simulating Operation of a Planetary Rover" (NPO-30722), *NASA Tech Briefs*, Vol. 28, No. 9 (September 2004), page 52. ROAMS simulates the operation of a robotic vehicle (rover) exploring terrain on a remote planet.] The images are needed for modeling responses of rover cameras that provide sensory inputs for machine-vision-based algorithms for controlling the motion of the rover. The augmented image-synthesizing part of the ROAMS software supports terrain geometry and texture specifiable by the user, CAHV and CAHVOR camera models, and more-realistic shadowing (see figure). (The letters in "CAHV" represent vectors in a standard photogrammetric model of a pinhole camera. Letters O and R in "CAHVOR" represent vectors used to model distortions.) A contemplated future version of ROAMS would support the CAHVORE model, which represents more-general cameras, including those having fish-eye or other wide-field-of-view lenses. (Letter E in "CAHVORE" represents a vector used to model apparent motion of a camera entrance pupil.)

This program was written by Richard Madison, Abhinandan Jain, and Marc Pomerantz 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42406.

Examples of Shadowing show terrain and rover shadows. Pixels that do not have direct line-of-sight to the Sun are darkened.

Improving UDP/IP Transmission Without Increasing Congestion

NASA's Jet Propulsion Laboratory, Pasadena, California

Datagram Retransmission (DGR) is a computer program that, within certain limits, ensures the reception of each datagram transmitted under the User Datagram Protocol/Internet Protocol. [User Datagram Protocol (UDP) is considered unreliable because it does not involve a reliability-ensuring connection-initiation dialogue between sender and receiver. UDP is well suited to issuing of many small messages to many different receivers.] Unlike prior software for ensuring reception of UDP datagrams, DGR does not contribute to network congestion by retransmitting data more frequently as an ever-increasing number of messages and acknowledgements is lost. Instead, DGR does just the opposite: DGR includes an adaptive timeout-interval-computing component that provides maximum opportunity for reception of acknowledgements, minimizing retransmission. By monitoring changes in the rate at which message-transmission transactions are completed, DGR detects changes in the level of congestion and responds by imposing varying degrees of delay on the transmission of new messages. In addition, DGR maximizes throughput by not waiting for acknowledgement of a message before sending the next message. All DGR communication is asynchronous, to maximize efficient utilization of network connections. DGR manages multiple concurrent datagram transmission and acknowledgement conversations.

This program was written by Scott Burleigh 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40868.

FORTRAN Versions of Reformulated HFGMC Codes

John H. Glenn Research Center, Cleveland, Ohio

Several FORTRAN codes have been written to implement the reformulated version of the high-fidelity generalized method of cells (HFGMC). Various aspects of the HFGMC and its predecessors were described in several prior *NASA Tech Briefs* articles, the most recent being "HFGMC Enhancement of MAC/GMC" (LEW-17818-1), *NASA Tech Briefs*, Vol. 30, No. 3 (March 2006), page 34. The HFGMC is a mathematical model of micromechanics for simulating stress and strain responses of fiber/matrix and other composite materials. The HFGMC overcomes a major limitation of a prior version of the GMC by accounting for coupling of shear and normal stresses and thereby affords greater accuracy, albeit at a large computational cost. In the reformulation of the HFGMC, the issue of computational efficiency was addressed: as a result, codes that implement the reformulated HFGMC complete their calculations about 10 times as fast as do those that implement the HFGMC. The present FORTRAN implementations of the reformulated HFGMC were written to satisfy a need for compatibility with other FORTRAN programs used to analyze structures and composite materials. The FORTRAN implementations also afford capabilities, beyond those of the basic HFGMC, for modeling inelasticity, fiber/matrix debonding, and coupled thermal, mechanical, piezo, and electromagnetic effects.

These programs were written by Steven M. Arnold of **Glenn Research Center** *and Jacob Aboudi and Brett A. Bednarcyk of Ohio Aerospace Institute. 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, Innovative Partnerships Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17960-1.

Program for Editing Spacecraft Command Sequences

NASA's Jet Propulsion Laboratory, Pasadena, California

Sequence Translator, Editor, and Expander Resource (STEER) is a computer program that facilitates construction of sequences and blocks of sequences (hereafter denoted generally as sequence products) for commanding a spacecraft. STEER also provides mechanisms for translating among various sequence product types and quickly expanding activities of a given sequence in chronological order for review and analysis of the sequence. To date, construction of sequence products has generally been done by use of such clumsy mechanisms as text-editor programs, translating among sequence product types has been challenging, and expanding sequences to time-ordered lists has involved arduous processes of converting sequence products to "real" sequences and running them through Class-A software (defined, loosely, as flight and ground software critical to a spacecraft mission). Also, heretofore, generating sequence products in standard formats has been troublesome because precise formatting and syntax are required. STEER alleviates these issues by providing a graphical user interface containing intuitive fields in which the user can enter the necessary information. The STEER expansion function provides a "quick and dirty" means of seeing how a sequence and sequence block would expand into a chronological list, without need to use of Class-A software.

This program was written by Roy Gladden, Bruce Waggoner, Mark Kordon, Mahnaz Hashemi, David Hanks, and Jose Salcedo 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41175.

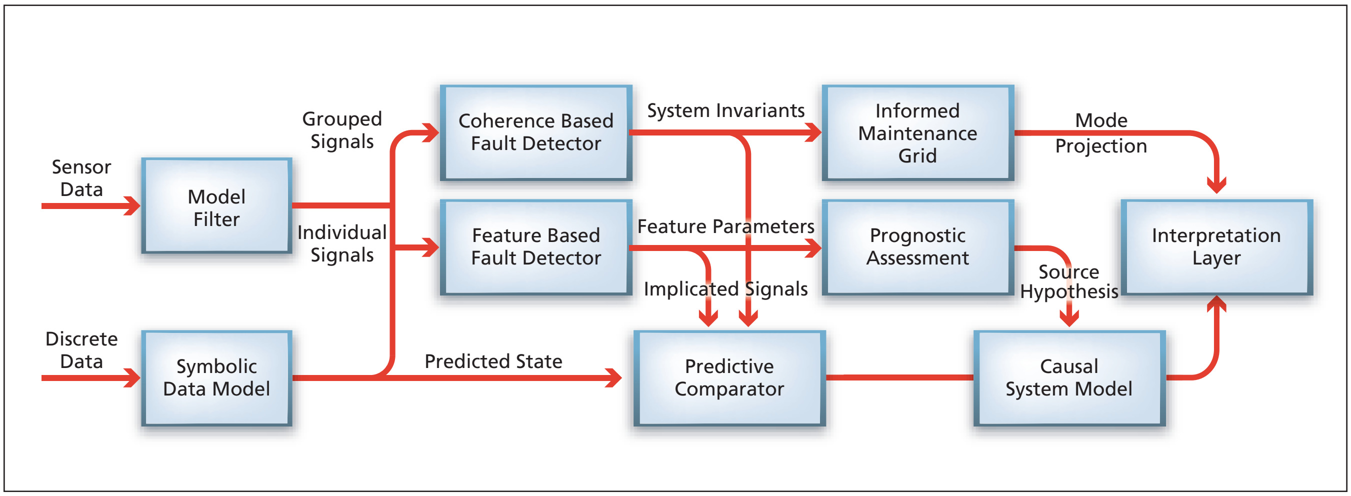
Flight-Tested Prototype of BEAM Software

NASA's Jet Propulsion Laboratory, Pasadena, California

Researchers at JPL have completed a software prototype of BEAM (Beacon-based Exception Analysis for Multi-missions) and successfully tested its operation in flight onboard a NASA research aircraft. BEAM (see *NASA Tech Briefs,* Vol. 26, No. 9; and Vol. 27, No. 3) is an ISHM (Integrated Systems Health Management) technology that automatically analyzes sensor data and classifies system behavior as either nominal or anomalous, and further characterizes anomalies according to strength, duration, and affected signals. BEAM (see figure) can be used to monitor a wide variety of physical systems and sensor types in real time. In this series of tests, BEAM monitored the engines of a Dryden Flight Research Center F-18 aircraft, and performed onboard, unattended analysis of 26 engine sensors from engine startup to shutdown. The BEAM algorithm can detect anomalies based solely on the sensor data, which includes but is not limited to sensor failure, performance degradation, incorrect operation such as unplanned engine shutdown or flameout in this example, and major system faults. BEAM was tested on an F-18 simulator, static engine tests, and 25 individual flights totaling approximately 60 hours of flight time. During these tests, BEAM successfully identified planned anomalies (in-flight shutdowns of one engine) as well as minor unplanned anomalies (e.g., transient oil- and fuel-pressure drops), with no false alarms or suspected false-negative results for the period tested. BEAM also detected previously unknown behavior in the F-18 compressor section during several flights. This result, confirmed by direct analysis of the raw data, serves as a significant test of BEAM's capability.

This program was written by Ryan Mackey, Raffi Tikidjian, Mark James, and David Wang 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42727.



Top-Level BEAM Architecture is used for monitoring physical systems in real time.

Mission Scenario Development Workbench

NASA's Jet Propulsion Laboratory, Pasadena, California

The Mission Scenario Development Workbench (MSDW) is a multidisciplinary performance analysis software tool for planning and optimizing space missions. It provides a number of new capabilities that are particularly useful for planning the surface activities on other planets. MSDW enables rapid planning of a space mission and supports flight-system and scientific-instrumentation trades. It also provides an estimate of the ability of flight, ground, and science systems to meet high-level mission goals and provides means of evaluating expected mission performance at an early stage of planning in the project life cycle. In MSDW, activity plans and equipment-list spreadsheets are integrated with validated parameterized simulation models of spacecraft systems. In contrast to traditional approaches involving worst-case estimates with large margins, the approach embodied in MSDW affords more flexibility and more credible results early in the lifecycle through the use of validated, variable-fidelity models of spacecraft systems. MSDW is expected to help maximize the scientific return on investment for space missions by understanding early the performance required to have a successful mission while reducing the risk of costly design changes made at late stages in the project life cycle.

This program was designed and written by Mark Kordon, John Baker, John Gilbert, David Hanks, and Dan Mandutianu of Caltech for **NASA's Jet Propulsion Laboratory** *and David Hooper of Emaginit. Further information is contained in a TSP (see page 1).*

This software is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41382.

Marsviewer

NASA's Jet Propulsion Laboratory, Pasadena, California

Marsviewer is a multi-platform application designed to aid in quality control, browsing, and analysis of original science product images (Experiment Data Records, or EDRs) and derived image data products (Reduced Data Records, or RDRs) returned by the Mars Explorer Rover (MER) mission. Marsviewer offers an abstraction of the products' organization via a "file finder." For example, the application "understands" the file structure and filename conventions of the MER Operational Storage Server, helping the user to navigate this complex file system to find desired images. Marsviewer also works with a flat file system, remote-operations file systems, image-archive file systems, and others. All EDRs found for a given solar day (Sol) are displayed in a list, optionally with thumbnail images. Once the user selects an image from the list, a tabbed pane conveniently displays the original source image and all associated RDRs. Marsviewer provides the option of overlaying derived images upon the source image, resulting in an easier-to-interpret color representation of the data. Display manipulations such as zoom, data range adjustment, contrast enhancement, and contour control are available. Image metadata (labels) from the current image can be displayed and searched. The architecture of the program is extensible: new types of RDRs can be installed and new file finders can be added to adapt the program to different file structures and different filename conventions. This keeps the application flexible and provides an opportunity for reuse with future rover missions.

This program was written by Nicholas Toole and Robert Deen 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-40852.

Tool for Analysis and Reduction of Scientific Data

NASA's Jet Propulsion Laboratory, Pasadena, California

The Automated Virtual Laboratory Tool (AVLT) is designed to be an intelligent scientific analysis assistant (SAA) system, dedicated to facilitating analysis and reduction of data collected by spaceborne scientific instruments. Within the SAA, a variety of conventional and artificial-intelligence software tools are integrated into a uniform system architecture. The AVLT interfaces with the user through a sophisticated graphical user interface that is part of the SAA environment. Functions of the AVLT include the following:

- Understanding the formats of input data files and automatically translating the files into whatever other formats are required for processing by analysis functions provided by users;
- Providing a graphical workspace, and assistance in using the workspace, wherein scientists can create computational experiments for exploration of data, formation of hypotheses, application of analysis functions, interpretation, and presentation, using concepts that are familiar within the scientists' domains of specialty;
- Providing a subsystem for planning a multistep analysis process to attain a goal based partly on prior computational experiments or on *a priori* knowledge;
- Constructing a knowledge base of data-exploration methods and analysis and interpretation algorithms; and
- Providing sophisticated graphical-presentation software to assist in visualization of data.

This program was written by Mark James 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42514.

ASPEN Version 3.0

NASA's Jet Propulsion Laboratory, Pasadena, California

The Automated Scheduling and Planning Environment (ASPEN) computer program has been updated to version 3.0. ASPEN as a whole (up to version 2.0) has been summarized, and selected aspects of ASPEN have been discussed in several previous *NASA Tech Briefs* articles. Restated briefly, ASPEN is a modular, reconfigurable, application software framework for solving batch problems that involve reasoning about time, activities, states, and resources. Applications of ASPEN can include planning spacecraft missions, scheduling of personnel, and managing supply chains, inventories, and production lines. ASPEN 3.0 can be customized for a wide range of applications and for a variety of computing environments that include various central processing units and random-access memories. Domain-specific reasoning modules (e.g., modules for determining orbits for spacecraft) can easily be plugged into ASPEN 3.0. Improvements over other, similar software that have been incorporated into ASPEN 3.0 include a provision for more expressive time-line values, new parsing capabilities afforded by an ASPEN language based on Extensible Markup Language, improved search capabilities, and improved interfaces to other, utility-type software (notably including MATLAB).

This program was written by Gregg Rabideau, Steve Chien, Russell Knight, Steven Schaffer, Daniel Tran, Benjamin Cichy, and Robert Sherwood 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41986.

Secure Display of Space-Exploration Images

NASA's Jet Propulsion Laboratory, Pasadena, California

Java EDR Display Interface (JEDI) is software for either local display or secure Internet distribution, to authorized clients, of image data acquired from cameras aboard spacecraft engaged in exploration of remote planets. ("EDR" signifies "experimental data record," which, in effect, signifies image data.) Processed at NASA's Multimission Image Processing Laboratory (MIPL), the data can be from either near-real-time processing streams or stored files. JEDI uses the Java Advanced Imaging application program interface, plus input/output packages that are parts of the Video Image Communication and Retrieval software of the MIPL, to display images. JEDI can be run as either a standalone application program or within a Web browser as a servlet with an applet front end. In either operating mode, JEDI communicates using the HTTP(s) protocol(s). In the Web-browser case, the user must provide a password to gain access. For each user and/or image data type, there is a configuration file, called a "personality file," containing parameters that control the layout of the displays and the information to be included in them. Once JEDI has accepted the user's password, it processes the requested EDR (provided that user is authorized to receive the specific EDR) to create a display according to the user's personality file.

This program was written by Cecilia Cheng, Gillian Thornhill, and Michael McAuley 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 Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-41246.

Books & Reports

Digital Front End for Wide-Band VLBI Science Receiver

An upgrade to the very-long-baseline-interferometry (VLBI) science receiver (VSR) — a radio receiver used in NASA's Deep Space Network (DSN) — is currently being implemented. The current VSR samples standard DSN intermediate-frequency (IF) signals at 256 MHz and after digital down-conversion records data from up to four 16-MHz baseband channels. Currently, IF signals are limited to the 265-to-375-MHz range, and recording rates are limited to less than 80 Mbps. The new digital front end, denoted the Wideband VSR, provides improvements to enable the receiver to process wider bandwidth signals and accommodate more data channels for recording. The Wideband VSR utilizes state-of-the-art commercial analog-to-digital converter and field-programmable gate array (FPGA) integrated circuits, and fiber-optic connections in a custom architecture. It accepts IF signals from 100 to 600 MHz, sampling the signal at 1.28 GHz. The sample data are sent to a digital processing module, using a fiber-optic link for isolation. The digital processing module includes boards designed around an Advanced Telecom Computing Architecture (ATCA) industry-standard backplane. Digital signal processing implemented in FPGAs down-convert the data signals in up to 16 baseband channels with programmable bandwidths from 1 kHz to 16 MHz. Baseband samples are transmitted to a computer via multiple Ethernet connections allowing recording to disk at rates of up to 1 Gbps.

This work was done by Andre Jongeling, Elliott Sigman, Robert Navarro, Charles Goodhart, Steve Rogstad, Kumar Chandra, Sue Finley, Joseph Trinh, Melissa Soriano, Les White, and Robert Proctor of Caltech and Benno Rayhrer (contractor) for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).* .
NPO-41191

Multifunctional Tanks for Spacecraft

A document discusses multifunctional tanks as means to integrate additional structural and functional efficiencies into designs of spacecraft. Whereas spacecraft tanks are traditionally designed primarily to store fluids and only secondarily to provide other benefits, multifunctional tanks are designed to simultaneously provide multiple primary benefits. In addition to one or more chamber(s) for storage of fluids, a multifunctional tank could provide any or all of the following:

- Passageways for transferring the fluids;
- Part or all of the primary structure of a spacecraft;
- All or part of an enclosure;
- Mechanical interfaces to components, subsystems, and/or systems;
- Paths and surfaces for transferring heat;
- Shielding against space radiation;
- Shielding against electromagnetic interference;
- Electrically conductive paths and surfaces; and
- Shades and baffles to protect against sunlight and/or other undesired light.

Many different multifunctional-tank designs are conceivable. The design of a particular tank can be tailored to the requirements for the spacecraft in which the tank is to be installed. For example, the walls of the tank can be flat or curved or have more complicated shapes, and the tank can include an internal structure for strengthening the tank and/or other uses.

This work was done by David H. Collins, Joseph C. Lewis, and Paul D. MacNeal of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-41407

Lightweight, Segmented, Mostly Silicon Telescope Mirror

A document presents the concept of a curved telescope primary reflector structure, made mostly of silicon, that would have an areal mass density ≤ 1 kg/m^2 and would be deployed in outer space, where it would be operated at a temperature in the cryogenic range. The concept provides for adjustment of the shape of the mirror to maintain the required precise optical surface figure despite the flexibility inherent in the ultra-lightweight design. The structure would include a thin mirror layer divided into hexagonal segments supported by flexure hinges on a lightweight two-layer backing structure. Each segment would also be supported at three points by sets of piezoelectric linear microactuators that could impose small displacements along the optical axis. The excitations applied to the aforementioned microactuators would be chosen to effect fine adjustments of the axial positions and the orientations of the segments relative to the supporting structure. Other piezoelectric linear microactuators embedded in the backing structure would enable control of the displacements of the segments along the hexagonal axes; they would also enable control of the curvature of the backing structure and, thus, additional control of the curvature of the reflector.

This work was done by Eui-Hyeok Yang of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-42106

Assistant for Analyzing Tropical-Rain-Mapping Radar Data

A document is defined that describes an approach for a Tropical Rain Mapping Radar Data System (TDS). TDS is composed of software and hardware elements incorporating a two-frequency spaceborne radar system for measuring tropical precipitation. The TDS would be used primarily in generating data products for scientific investigations. The most novel part of the TDS would be expert-system software to aid in the selection of algorithms for converting raw radar-return data into such primary observables as rain rate, path-integrated rain rate, and surface backscatter. The expert-system approach would address the issue that selection of algorithms for processing the data requires a significant amount of preprocessing, non-intuitive reasoning, and heuristic application, making it infeasible, in many cases, to select the proper algorithm in real time. In the TDS, tentative selections would be made to enable conversions in real time. The expert system would remove straightforwardly convertible data from further consideration, and would examine ambiguous data, performing analysis in depth to determine which algorithms to select. Conversions performed by these algorithms, presumed to be correct, would be compared with the corresponding real-time conversions. Incorrect real-time conversions would be updated using the correct conversions.

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

The software used in this innovation is available for commercial licensing. Please contact Karina Edmonds of the California Institute of Technology at (626) 395-2322. Refer to NPO-42515.

Anion-Intercalating Cathodes for High-Energy-Density Cells

A report discusses physicochemical issues affecting a fluoride-intercalating cathode that operates in conjunction with a lithium ion-intercalating anode in a rechargeable electrochemical cell described in a cited prior report. The instant report also discusses corresponding innovations made in solvent and electrolyte compositions since the prior report. The advantages of this cell, relative to other lithium-ion-based cells, are said to be greater potential (5 V vs. 4 V), and greater theoretical cathode specific capacity (0.9 to 2.2 A-h/g vs. about 0.18 A-h/g). The discussion addresses a need for the solvent to be unreactive toward the lithium anode and to resist anodic oxidation at potentials greater than about 4.5 V vs. lithium; the pertinent innovation is the selection of propylene carbonate (PC) as a solvent having significantly more stability, relative to other solvents that have been tried. The discussion also addresses the need for an electrolyte additive, denoted an anion receptor, to complex the fluoride ion; the pertinent innovation is the selection of tris(hexafluoroisopropyl) borate as a superior alternative to the prior anion receptor, which was tris(pentafluorophenyl) borate.

This work was done by William West 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:

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

Refer to NPO-42316, volume and number of this NASA Tech Briefs *issue, and the page number.*

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