National Aeronautics and
Space Administration

Nanotechnology for the Automotive Industry

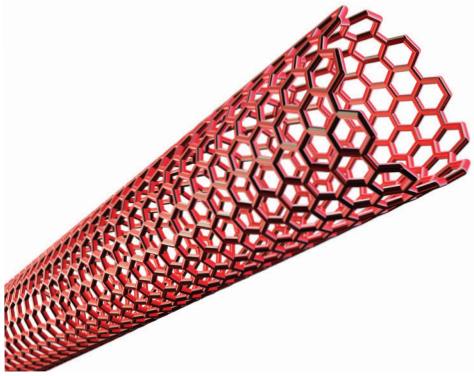
High-speed, low-power consumption, flexible electronic circuitry for automotive applications

TECHNOLOGY OPPORTUNITY

Innovators at NASA's Glenn Research Center have developed a suite of nanotechnologies that offer the potential to enhance or replace silicon-based technology for high-speed, high-computing power devices that operate at low voltage and current levels. These nanotechnologies are used to make polymer nanowires, carbon nanotubes (CNTs), and other nanoionic structures, that produce a variety of nanoscale electronic switches, which are the basic building blocks for relatively inexpensive, low-voltage, and high-speed logic circuits. The nanotechnologies are more durable, with longer lasting circuits, and they enable computational capabilities at specific locations. The circuits can be used to make sensing systems, wireless and embedded communications, large area flexible electronic displays, active matrix light-emitting diode (LED) displays, along with antennas and radiofrequency identification (RFID) devices such as smart keys and smart cards.

BENEFITS

- **Enhanced capabilities:** Greater versatility for radiofrequency (RF) transmissions than traditional silicon-based semiconductor devices
- **Robust:** No moving parts for longer life and higher mean time before failure (MTBF) than microelectromechanical's (MEM's)
- **Versatile:** Could be tailored as single primary operational component or as redundant communications and sensing components for a variety of automobile applications
- **Lower cost:** Simpler to produce than traditional silicon-based semiconductors and microelectromechanical system (MEMS) devices
- **Efficient:** Power consumption significantly below that of MEM's (1 volt versus 50 to 60 volts for MEM's)



APPLICATIONS

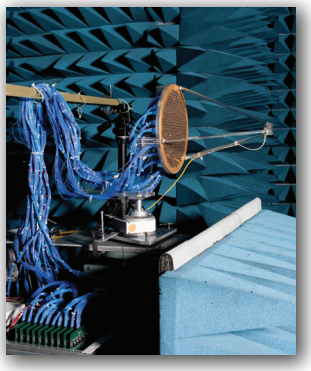
- Localized electronic sensing and computational capability in engines, tires, or windows (e.g., to adjust tints/shades)
- Improved self-monitoring and diagnostic capabilities for fuel consumption, emissions, etc.
- Communications and data storage circuitry can be embedded into vehicle surfaces (e.g., multifunctional embedded nanoantennas for wireless reception, including radio, Wi-Fi, cell-phone), navigation (e.g., Global Positioning System (GPS)), and collision avoidance systems (small scale favorable for circuit development at 77 GHz).
- Advanced active technology for smart keys and safety devices (e.g., reversible-sensing and electronic-circuitry-protection elements)

HOW IT WORKS

A family of experimental, highly miniaturized field-effect transistors (FETs) is based on exploitation of the electrical properties of nanofibers of polyaniline/polyethylene oxide (PANi/PEO) doped with camphorsulfonic acid. These polymer-based FETs can become building blocks of relatively inexpensive, low-voltage, and high-speed logic circuits that could supplant complementary metal oxide/semiconductor (CMOS) logic circuits. These polymer-based FETs offer advantages over competing FETs based on carbon nanotubes. Whereas it is difficult to control the molecular structures and, hence, the electrical properties of carbon nanotubes, it is easy to tailor the electrical properties of these polymer-based FETs through choices of doping levels and chemical manipulation of polymer side chains. A further advantage of doped PANi/PEO nanofibers is that they can be made to draw very small currents and operate at low voltage levels, and thus are promising for applications that require the use of many FETs to obtain large computational capabilities while minimizing power demands.

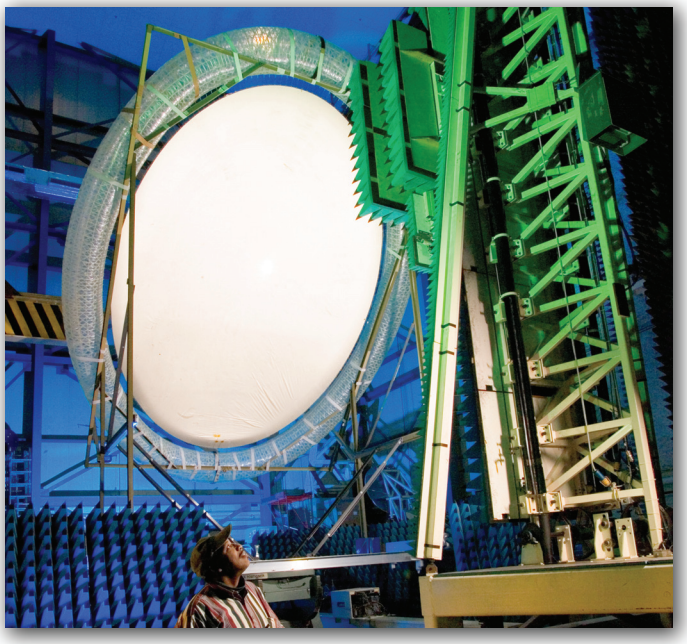
Logic functions—the building blocks of computational and switching capabilities—can be combined with miniaturized autonomous automotive sensing systems to control fuel consumption, emissions, cabin temperature control, and more. The split-gate architecture for logic circuitry is demonstrated via a two-input logic AND circuit. For all combinations of VGS1 and VGS2, except VGS1 = VGS2 = –10 V, the transistor is in the resistive "OFF" state. That is, for VGS1= VGS2 – 10 V, the transistor is in the more conductive "ON" state. When the device functions as an AND logic circuit, VGS1 and VGS2 are functions of time, while corresponding change in the output of voltage VR is a function of time for the four possible combinations of VGS1 and VGS2 = 0 or –10 V. Larger outputs are observed only when both gates are simultaneously biased "high."

NASA has also developed a related technology—nanoionics-based switches—that can incorporate relatively large amounts of metal and behave as solid electrolytes. The ionic conductivity of such a material can be of the same order of magnitude as the electronic conductivity of a semiconductor. This technology is a reversible electrochemical switch that can have geometric features as small as nanometers.



WHY IT IS BETTER

NASA's innovative technology overcomes several of the challenges inherent in MEMS-based and solid-state-based devices. The nanotechnologies offer low power circuitry for applications such as digital electronics and sensors, especially where computing power is needed but power is limited. They provide better performance in RF applications and enable miniaturization of onboard automotive electrical sensing and control systems. Because they have no moving parts, they provide more reliable and mechanically robust automobile electronics with higher MTBF.



LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Dual Input and Gate Fabricated From a Single Channel Poly (3-Hexylthiophene) Thin Film Field Effect Transistor (LEW–18214–1), the Electrospun Polyaniline/Polyethylene Oxide Nanofiber Field Effect Transistor (LEW–17933–1), and the Nanoionics-Based Switches for Radio Frequency Applications (LEW–18313–1).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
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Novel Nanoionic Radiofrequency Switches

Compact, robust, and reliable nanoelectronic circuitry for automotive applications

TECHNOLOGY OPPORTUNITY

Scientists at NASA's Glenn Research Center have developed nanoionics-based radiofrequency (RF) switches for use in communications, sensing, and control systems in automotive vehicles. These innovative nanoionic devices have the potential to replace microelectromechanical systems (MEMS) and conventional RF semiconductor devices in automotive systems. Nanoionic switches offer the superior RF performance and low power consumption found in MEMS switches, with higher reliability and without the need for higher electrical voltages. Nanoionics-based RF switches also offer the durability, high-speed operation, and low cost of semiconductor devices.

BENEFITS

- **Low power:** Requires 1 volt versus 50 to 60 volts for microelectromechanical's (MEM's)
- **Lower cost:** Less expensive than MEMS and uses conventional integrated-circuit fabrication techniques, with as little as five processing steps
- **Simpler:** Nonvolatile—meaning no power is required to maintain a particular state (e.g., ON or OFF)
- **Faster:** Comparable in speed to solid-state electronics
- **Rugged:** Maintains superior performance as compared to a mechanical connection
- **Reliable:** Has no moving parts, providing greater reliability and longer mean time before failure (MTBF)
- **Better RF performance:** Has the potential to circumvent RF performance limitations associated with solid-state switches

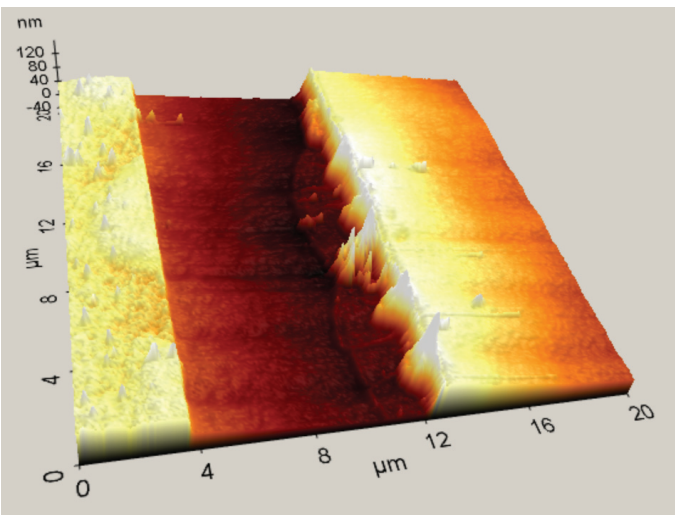
APPLICATIONS

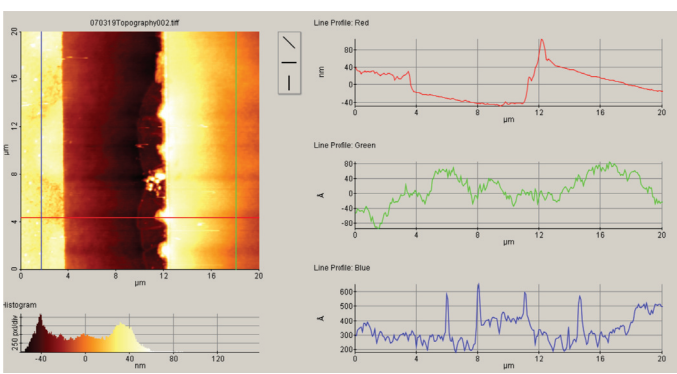
- Conformal antennas for collision avoidance systems (e.g., ranging and autonomous deceleration) and navigation (e.g., Global Positioning System (GPS))
- Communications and data storage
- Smart keys and safety devices
- Automotive sensing and diagnostic systems (e.g., engine performance, fuel consumption, emissions, cabin temperature control, tires, windows, etc.)

HOW IT WORKS

Nanoionic switches exploit the properties of some amorphous materials that can incorporate relatively large amounts of metal and behave as solid electrolytes. The ionic conductivity of such a material can be of the same order of magnitude as the electronic conductivity of a semiconductor. Ions are formed at an anode and migrate into the solid electrolyte while electrons are injected from a cathode, thereby causing the growth of metal nanowires through the electrolyte from the cathode to the corresponding anode.

Once a nanowire has grown sufficiently to form an electrically conductive path between the electrodes, there is no need to continue to apply electric power to maintain the connection. The process of making the connection can easily be reversed by applying a reverse bias to re-oxidize the metal atoms in the solid electrolyte to recreate the insulating amorphous layer. Thus, a nanoionics-based switch is a reversible electrochemical switch that can have geometric features as small as nanometers. The process time for making or breaking the connection is about a nanosecond.





Electrochemical switch—before turn-on.

WHY IT IS BETTER

- Nanotechnologies collect, process, and communicate more data than conventional semiconductor and MEMS devices with less size, weight, and power consumption.
- Reliable, durable, and low-cost nano-electronic circuitry can be embedded into a vehicle's wireless communications, navigation, entertainment, and onboard sensing systems to improve performance and enhance product features and benefits.
- Inexpensive, low-voltage, high-speed nano-electronic logic circuits have better RF performance than conventional semiconductor devices.

PATENTS

Glenn has patented this technology (U.S. Patent No. 7,923,715).

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Nanoionics-Based Switches for Radio Frequency Applications (LEW–18313–1).

FOR MORE INFORMATION

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Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
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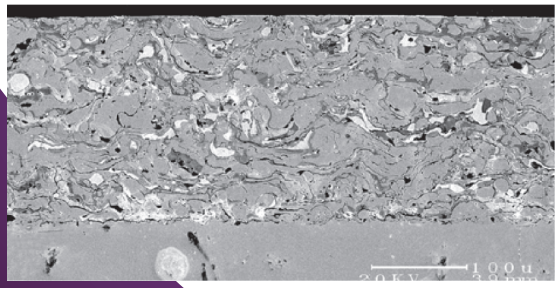
OIL-FREE TURBOMACHINERY—FOIL GAS BEARINGS

TECHNOLOGY OPPORTUNITY

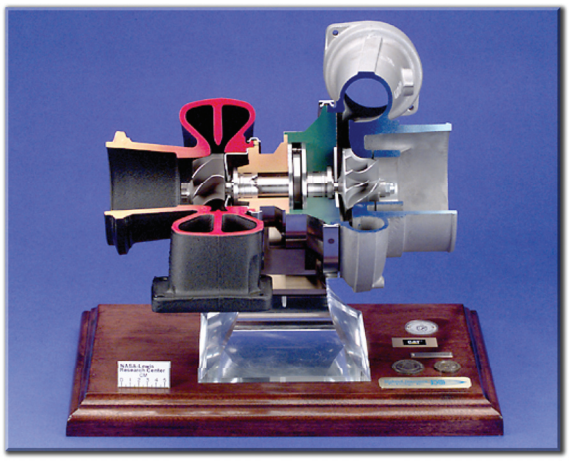
NASA Glenn's Oil-Free Turbomachinery research team has developed foil gas bearing technology and know-how that enables the commercialization of a broad array of revolutionary Oil-Free gas turbines, compressors, blowers, motors, and other rotating machines that can operate from cryogenic to red-hot temperatures.

BENEFITS

- Foil gas bearings use no oil and operate without maintenance leading to simple designs and often substantial weight savings.
- Foil gas bearings rely on a hydrodynamic (self-generated) gas film for lubrication and do not need external pressurization. Any ambient gas serves as the lubricant.
- Foil gas bearings have no rolling elements and thus eliminate ball bearing imposed shaft speed (DN) limits allowing machinery to run faster and longer.
- NASA patented PS300 and PS400 coatings enable operation to 650 °C and beyond, conventional polytetrafluoroethylene (PTFE)-based coatings provide low cost path for bearings for use to 300 °C.
- A substantial technology push over the last two decades has greatly "demystified" this valuable technology and provides simple path to commercialization. Public domain know-how covers bearing design, manufacturing, coatings, testing, and applications.



Cross section of PS304 coating.



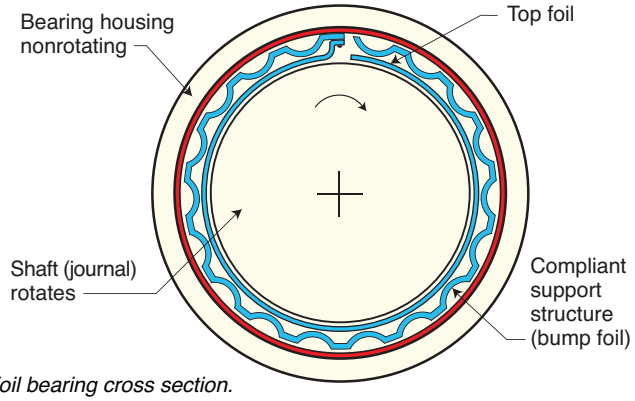
Cutaway view of world's first Oil-Free turbocharger.

COMMERCIAL APPLICATIONS

- Oil-Free foil bearings have been commercialized in aircraft air cycle machines (ACMs) for cabin pressurization and cooling, in cryogenic turbo-compressors, and microturbine electrical generators (15 to 250 kWe).
- Emerging applications include Oil-Free turbo-chargers for cars and trucks, larger turbine generators, General Aviation (GA), BizJet, unmanned aerial vehicles (UAVs), and missile engines.
- Future applications are anticipated in auxiliary power units (APUs), regional jet and helicopter engines, revolutionary aeropropulsion engines, space power systems and launch vehicle cryo-genic turbomachinery.
- Near-term markets include Oil-Free wastewater aeration blowers, industrial blowers and point-of-use air compressors, electrically driven automotive superchargers, fuel cell blowers, and hybrid power train microturbines.

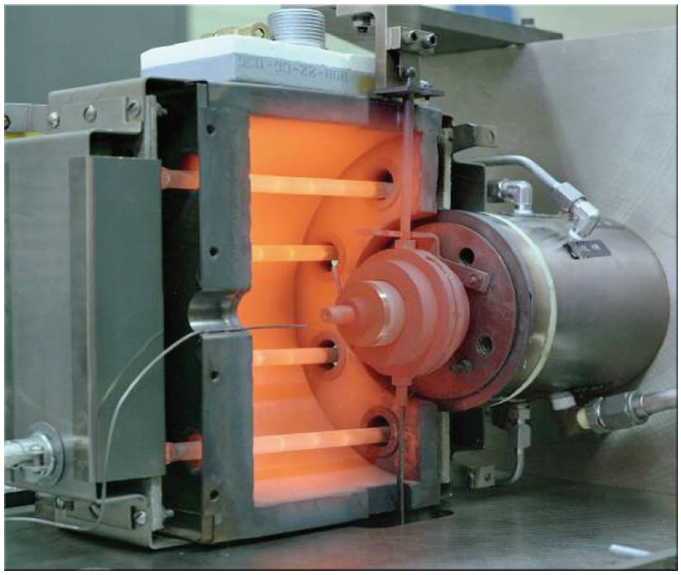
TECHNOLOGY DESCRIPTION

Oil-Free foil gas bearings are self-acting hydrodynamic bearings that are ideal for high-speed, lightly loaded shaft support. During initial startup, the bearing surfaces, made up of thin sheet metal foils, rub lightly and solid lubricants must be used to reduce friction and wear. At high speeds, a gas film forms that separates the shaft from the foils providing a low friction, wear-free bearing. This design requires no external pressurization. Since air cannot burn like oil, foil bearings can operate at high speeds (no bearing DN limit) over a wide temperature range and tolerate misalignment and distortion.



Foil bearing cross section.

Foil bearings have long been used in aircraft cabin cooling and pressurization compressors where their intrinsic "Oil-Free" characteristic has been paramount. Research at NASA Glenn and elsewhere over the last two decades has greatly enhanced foil bearing capability and application know-how resulting in many new uses and applications. Our technical staff has continuously published our findings in the open literature greatly aiding the industrial development of Oil-Free microturbine generators, turbochargers and other high speed rotating machines operating on foil gas bearings.



Red-hot foil bearing.

OPTIONS FOR COMMERCIALIZATION

NASA has strived to disseminate sufficient information to enable multiple entities membership in the Oil-Free community. Numerous industry sources for foil air bearings now exist that are eager and capable of assisting OEMs and suppliers to apply this technology to rotating systems. Many bearings designs, some still under patent protection and others no longer restricted, are available for development and use. Recently developed design guidelines, manufacturing details and processes, and modeling tools are now readily available. The NASA Glenn research team can provide guidance and is seeking opportunities for partnerships.

Typical turbocharger applications.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Oil-Free Turbomachinery Foil Gas Bearings.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
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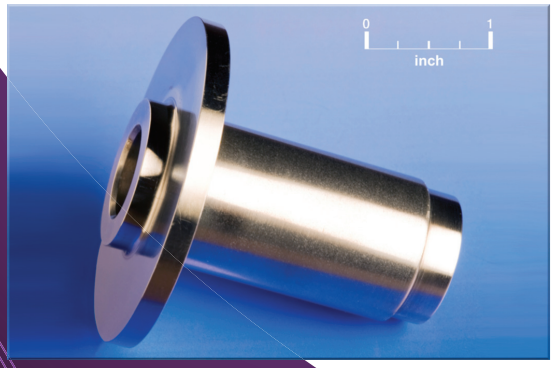
OIL-FREE TURBOMACHINERY—TRIBOMATERIALS

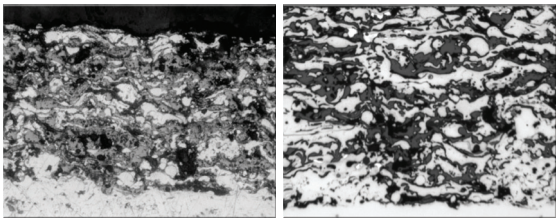
TECHNOLOGY OPPORTUNITY

NASA Glenn's Oil-Free Turbomachinery research team has developed high-temperature solid lubricant materials suitable for foil gas bearings that enable the commercialization of a broad array of revolutionary Oil-Free gas turbines, compressors, blowers, motors, and other rotating machines that can operate from cryogenic to red-hot temperatures. These tribological (friction and wear) coatings and composite powder metallurgy material innovations have immediate and proven spinoff potential for high-temperature steam turbine control valves, exhaust gas recirculation (EGR) valves, articulating ducts and piping joints, and other industrial and aerospace applications.

BENEFITS

- PS300 and more recent PS400 solid lubricant coatings provide reduced friction and wear to any lightly loaded sliding mechanism operating from cryogenic to 650+°C.
- PS300 coated shafts operating against foil bearings have logged well over 100,000 start-stop cycles without wearing out resulting in a truly maintenance-free bearing.
- NASA PS300 coatings and PM300 powder metallurgy materials and related technology are freely available in the marketplace from licensed vendors.
- The constituents (ingredients) used in NASA PS/PM 300 and 400 materials are nontoxic and thermochemically stable. They are not water-soluble and have a low environmental impact.
- PS300 and PS400 coatings and composites are protected by U.S. patents and are available for licensing to help protect your technology investment.





Comparative cross section micrographs of PS304 (left) and PS400 (right) coatings showing a similar splat layered morphology typical for thermal spray coatings.

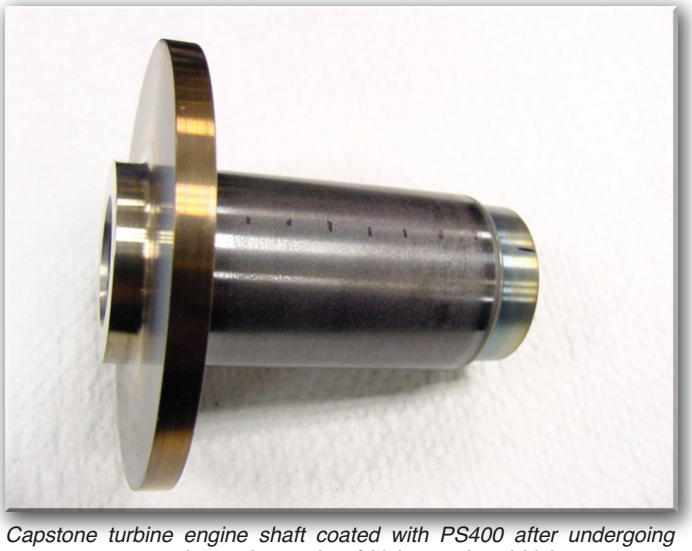
COMMERCIAL APPLICATIONS

- NASA PS300 coated shafts enable maintenance-free, high-temperature Oil-Free microturbine electrical generators (<100 kW).
- NASA PS400 coating (simplified composition) has a lower cost and is more dimensionally stable than predecessor PS300. PS400 has been proven durable in over 20,000 hours of turbine engine operation.
- PS300 used to lubricate high-temperature steam control valve lift rods in power plants worldwide for well over a decade and PM300 bushings provide long-life service in heat-treatment furnace conveyor systems.
- PS300/400 solid lubricant technology has direct applications to any high-temperature sliding contact. Automotive exhaust as recirculation (EGR) valves and aircraft bleed air valves, high-temperature ducting, and pipe supports are just a few examples.

Turbine engine shaft coated with PS400 after grinding.

TECHNOLOGY DESCRIPTION

Oil-Free foil bearings require innovative approaches to solid lubrication for start-stop sliding contact that occurs before the gas lubricating film forms. The PS300 and PS400 coatings and their powder metallurgy cousins are composites from a unique combination of metals, ceramics, and solid lubricant additives. Plasma spray coating deposition is used to apply a thick (0.010 inch) layer onto a metal surface that is then ground and polished before use. During rubbing contact, the lubricant phases migrate to the surface forming a lubricious glaze that prevents wear and reduces friction. Powder metallurgy techniques are used to make freestanding self-lubricating components such as bushings and wear plates whenever a coating is not convenient or possible (e.g., inside small diameter parts). These materials are made from thermochemically stable, nonsoluble, nontoxic constituents and typically include nickel, molybdenum, chrome oxide, silver, and barium fluoride-calcium fluoride eutectic. Compositions can be easily tailored for specific applications. Operation of machinery using these tribomaterials has been proven over decades of use from subfreezing to over 650 °C.



Capstone turbine engine shaft coated with PS400 after undergoing 2200 start-stop cycles and 8000 hr of high-speed and high-temperature operation. Dark shiny appearance is typical for the coating following a break-in period.

PS400 cross section sandwich samples. Top layer exposed to air at 760 °C for 15 hr. Lower layer as-deposited control coating. No microstructural or dimensional changes prove PS400's superior capabilities.

OPTIONS FOR COMMERCIALIZATION

NASA holds a patent (U.S. Patent No. 5,866,518) on the PS300 solid lubricant and has awarded nonexclusive licenses for raw materials production, powder metallurgy processing, and thermal spray coating deposition. Coating and composite samples are readily available from multiple commercial sources. A patent is pending on the more recent PS400 coating. Additional nonexclusive licensees are sought. Technical assistance for technology application is available from NASA technical and commercialization staff.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Oil-Free Turbomachinery—Tribomaterials (LEW–16183–1 and LEW–18561).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

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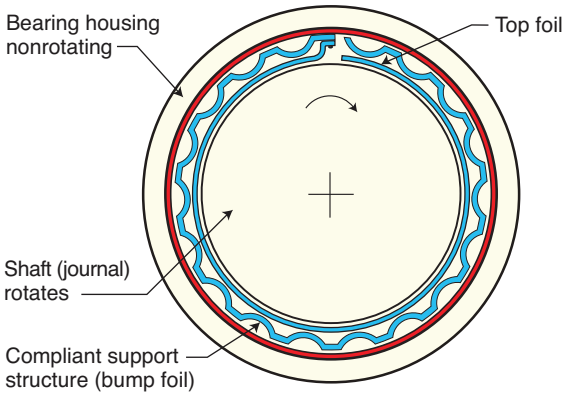
OIL-FREE TURBOMACHINERY—OIL-FREE MODELING

TECHNOLOGY OPPORTUNITY

NASA Glenn's Oil-Free Turbomachinery research team has pioneered and disseminated foil gas bearing models, tools, and techniques to assist in the industrial commercialization of a broad array of revolutionary Oil-Free gas turbines, compressors, blowers, motors, and other rotating machines. We have test capability to support industrial activities and guide development.

BENEFITS

- Foil gas bearings are deceptively simple devices that can be complex to understand and implement but research has resulted in several simple analytical models governing behavior, and computer-based tools exist to guide application.
- Foil gas bearing performance mirrors well understood hydrodynamic (self-generated) bearing operation when viewed within normal operating conditions (light load and high speed) allowing for first principle simple tool development.
- Substantial technology push over the last two decades has greatly "demystified" this valuable technology and provides a simple path to commercialization. Public domain know-how covers bearing design, manufacturing, coatings, testing, and applications.
- NASA-sponsored efforts have fostered the emergence of new foil bearing manufacturers providing multiple sources for the hardware, thus lowering costs and advancing performance.
- NASA expertise can be made available to partner with industry to learn to use foil gas bearings in future machines in a variety of ways including modeling work, feasibility studies, and experimental testing.



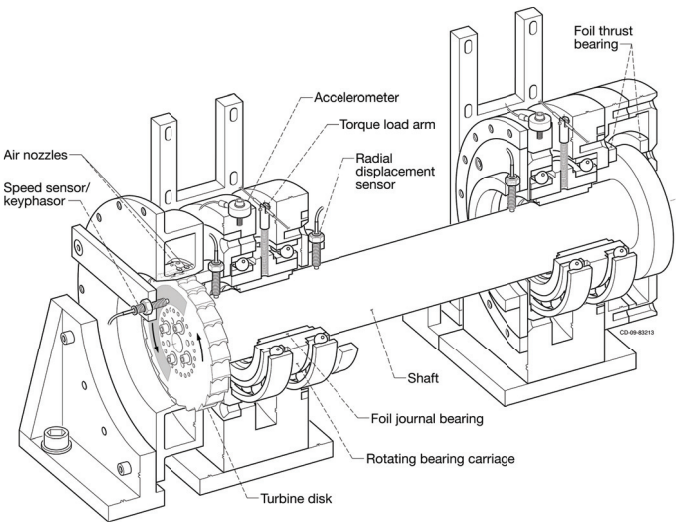
Foil journal bearing cross section. Models provide methods to predict load capacity, spring stiffness, and dynamic damping capabilities.

COMMERCIAL APPLICATIONS

- Oil-Free foil bearings have been commercialized in aircraft air cycle machines (ACMs) for cabin pressurization and cooling, cryogenic turbo-compressors, and microturbine electrical generators (15 to 250 kWe).
- Emerging applications include Oil-Free turbo-chargers for cars and trucks, larger turbine generators, general aviation (GA), BizJet, unmanned aerial vehicles (UAVs), and missile engines.
- Future applications are anticipated in auxiliary power units (APUs), regional jet and helicopter engines, revolutionary aeropropulsion engines, space power systems, and launch vehicle cryogenic turbomachinery.
- Near-term markets are emerging for Oil-Free wastewater aeration blowers, industrial blowers and point-of-use air compressors, electrically driven automotive superchargers, fuel cell blowers, and hybrid power train microturbines.

TECHNOLOGY DESCRIPTION

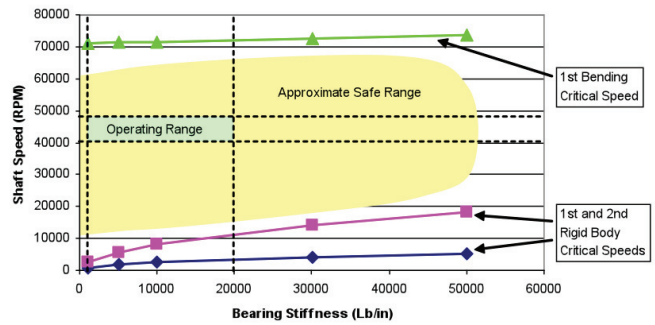
Historically, Oil-Free foil gas bearing design, performance prediction, and manufacturing have been confined to just a few industrial entities. For this reason, much confusion and misconceptions have arisen over their proper use and application. Research at NASA Glenn and elsewhere has resulted in simple algebraic modeling tools for bearing load capacity, stiffness, and damping that greatly aid foil bearing application to new rotor systems. Clearly written research papers describe the design and manufacturing process, and computer models are now available to predict rotordynamic stability of foil-bearing-supported machines. Put another way, there now exists adequate information for newcomers to the field to develop their own Oil-Free machines and reap the benefits.



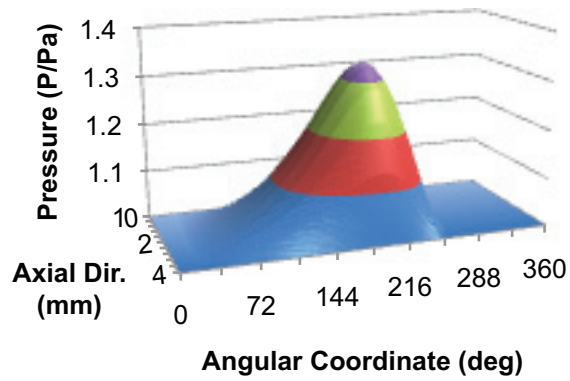
Experimental facilities for testing foil gas bearings including rotordynamic behavior, power loss, thermal management, and more.

OPTIONS FOR COMMERCIALIZATION

NASA has strived to disseminate sufficient information to enable multiple entities to participate in the development of Oil-Free machinery. Multiple industrial sources for foil air bearings now exist that are eager and capable of assisting Original Equipment Manufacturers (OEMs) and suppliers to apply this technology to rotating systems. Numerous bearing designs, some still under patent protection and others no longer restricted, are available for development and use. Further, recently developed design guidelines, manufacturing details and processes, and modeling tools are now readily available. The NASA Glenn research team can provide guidance and is seeking opportunities for partnerships.



Rotordynamic critical speed map for a proposed Brayton turboalternator using foil gas bearings.



Fluid-film pressure distribution inside a foil journal bearing as determined by a NASA-sponsored, University-developed design code.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Oil-Free Turbomachinery—Oil-Free Modeling.

FOR MORE INFORMATION

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Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
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Polymer Matrix Nanocomposites

To improve material durability, thermal stability, and mechanical performance of epoxy resins

TECHNOLOGY OPPORTUNITY

Researchers at NASA's Glenn Research Center have developed new methods for strengthening epoxy resins without diminishing toughness or altering existing processing procedures. The two related technologies both involve controlled placement and dispersion of nanoparticles within an epoxy matrix. One method (LEW–18474–1) includes selectively placing organically modified clays into an aromatic/alkoxy-blended resin to create a nanocomposite that provides increased strength and stiffness without sacrificing toughness in the cured epoxy or prepreg. A second method (LEW–18648–1) incorporates nanoparticles (clays and carbon nanofibers and nanotubes) into epoxy resins that have been processed with thermoplastic tougheners, thereby improving strength, ductility, glass transition temperature (Tg), and conductivity.

BENEFITS

- **Enhances performance:** Provides better strength, stiffness, ductility, and conductivity (when using carbon nanoparticles) without compromising toughness or Tg
- **Improves material yield stress:** Increases yield stress 40 to 100 percent while maintaining or improving toughness
- **Easy to implement:** During resin transfer molding, melt viscosity remains unchanged and material processing methods are unchanged
- **Simple and accessible method:** Uses commercially available starting materials and requires no special equipment
- **Enables more efficient and lightweight vehicles:** Toughened epoxies can reduce vehicle weight by 20 percent

APPLICATIONS

These technologies are beneficial for making composite structures that require strength and toughness. Potential applications include

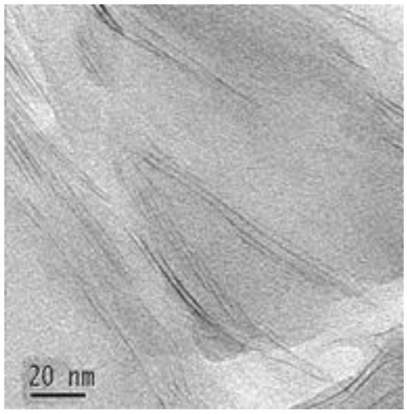
- Automotive body components (e.g., timing belt covers)
- Engine parts (e.g., turbines and fan blades)
- High-temperature engine structures
- Fuel cell storage tanks
- Composite tanks for high-pressure natural gas storage
- Ballistic impact armor

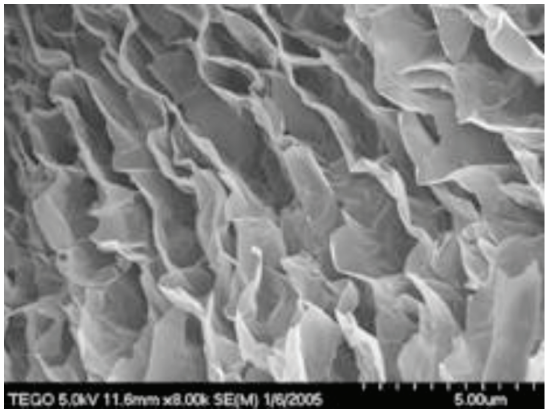
HOW IT WORKS

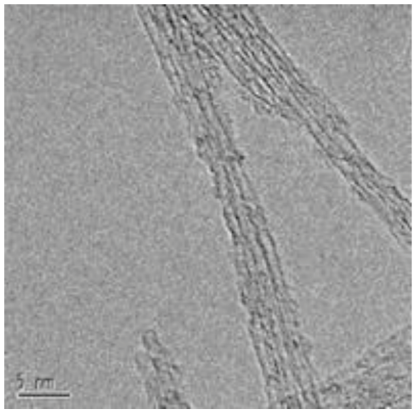
Nanoscale clays and graphene have been dispersed in a variety of polymer matrices for the purpose of improving their physical, thermal, and barrier performance. NASA has improved nanoparticle dispersion and compatibility with the matrix, leading to significant increases in thermal stability, oxidation resistance, and mechanical strength. The platelet morphology of both clay and graphene has provided considerable reductions in gas permeation through a polymer matrix. Because nanoparticle loadings typically range from 0.5 to 5 weight percent, the resulting composite is lightweight.

WHY IT IS BETTER

NASA's innovation improves upon the strength and modulus of an epoxy-clay nanocomposite while also improving (or maintaining) the resin toughness and ductility. The resulting nanocomposites also demonstrate reduced gas permeation and improved electrical and thermal conductivity. Recent improvements in barrier performance enable their use in polymer matrix composite gas tanks. The technology can also be used as a filler in polymer composites to improve strength and stiffness without adding weight.







PATENTS

Glenn has filed patent applications for this technology.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the polymer matrix nanocomposites (LEW–18474–1 and LEW–18648–1).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Advanced Single-Wall Carbon Nanotubes

State-of-the-art materials for manufacturing stronger, lighter weight, and custom-designed automotive components

TECHNOLOGY OPPORTUNITY

Scientists at NASA's Glenn Research Center have developed a method of modifying single-wall carbon nanotubes (SWCNTs) capable of exhibiting excellent dispersion within a polymer matrix. The resulting composite offers improved mechanical, thermal, and electrical properties for use in automotive applications (as compared to conventional polymers or polymers with unmodified SWCNTs). This technology provides better strength, stiffness, stability, and higher conductivity than conventional reinforcement materials. These ultralightweight, high-strength composite materials are ideal for fabrication of lighter weight race cars, automobile components, flywheels, and more.

BENEFITS

- **Lightweight:** Can increase efficiency and reduce fuel consumption 15 to 25 percent
- **Clean, green technology:** Requires no solvents
- **Higher tensile strength:** 100 times the strength of steel
- **Custom designed materials:** Offers a variety of user-specified mechanical, electrical, and thermal material properties
- **Higher glass transition temperatures:** Allows material to maintain its strength at higher temperatures
- **Increased conductivity:** Improves the power density of materials in electronic devices

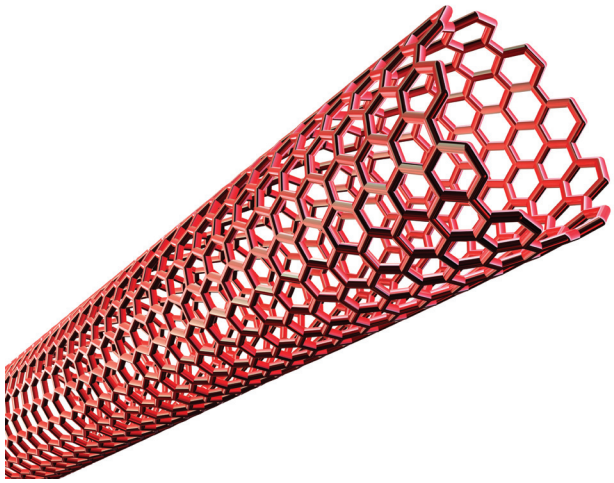
APPLICATIONS

These technologies are beneficial for making lightweight composite structures that require good strength and conductivity. Potential applications include:

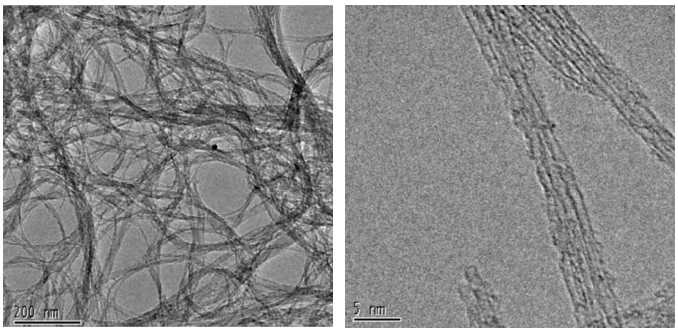
- High-performance race cars
- Lighter weight automobile components (e.g., chassis and body panels)
- Electrical cables and wires
- Ultracapacitors
- Flywheels
- Springs

HOW IT WORKS

A variety of polymers, including epoxies, have been used to prepare carbon nanotube (CNTs) polymer nanocomposites with the aim of obtaining enhanced mechanical, thermal, and electrical properties. An important requirement for the effective use of carbon nanotubes as reinforcements is the ability to homogenously disperse the nanotubes in the polymeric material. NASA has developed non-covalently modified single-wall carbon nanotubes that allow homogeneous dispersion of the SWCNTs throughout the polymeric resins. This aids in efficient load transfer, which is necessary for the desired improvement in mechanical properties, and also produces nanocomposites with optimum electrical conductivity.



Single-wall carbon nanotubes.



TEM, purified single-wall nanotubes.

WHY IT IS BETTER

Single-wall carbon nanotubes have the ability to behave like metals or semiconductors, conduct electricity better than copper, transmit heat better than diamond, and they rank among the strongest materials on Earth. NASA's modified SWCNTs allow better dispersion throughout the polymer matrix, which leads to superior properties in the resulting polymer composite. The resulting materials possess excellent strength, stiffness, stability, and high conductivity (both thermal and electrical). Their high modulus and low weight make SWCNTs ideal reinforcements in ultra lightweight, high-strength, and stiffness composite materials (e.g., high-performance race car components). In addition, the ability to enhance thermal and electrical conductivity as well as mechanical properties opens the possibility of utilizing SWCNTs in the development of multifunctional materials; e.g., for onboard electrical systems embedded in automotive body panels.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider partnerships with Glenn developing applications for its Advanced Single-Wall Carbon Nanotubes.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Lattice Block and Metallic Foam Materials

For lighter weight structures with improved strength, impact resistance, and noise reduction

TECHNOLOGY OPPORTUNITY

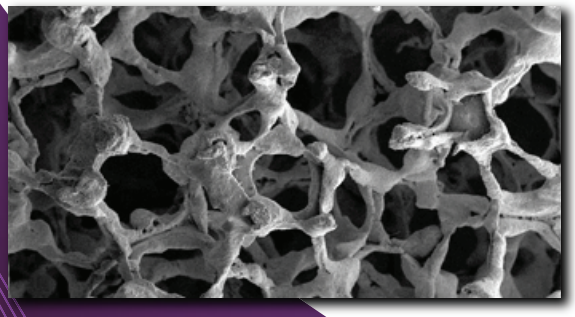
NASA's Glenn Research Center invites companies to establish partnerships to explore new applications for lattice block and/or metallic foam materials. Lattice block structures represent a significant advance in the state-of-the art of lightweight engineered structural components due to their ability to reduce weight while maintaining stiffness and strength. Metallic foam provides excellent impact resistance and noise suppression and can withstand high heat and extreme temperature variations. Originally developed for aerospace, these technologies have the capability to significantly enhance the performance of automotive components and systems.

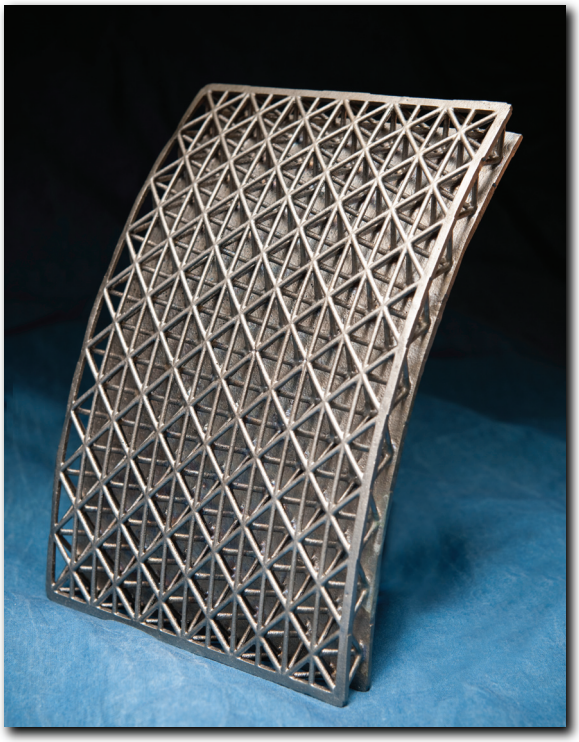
BENEFITS

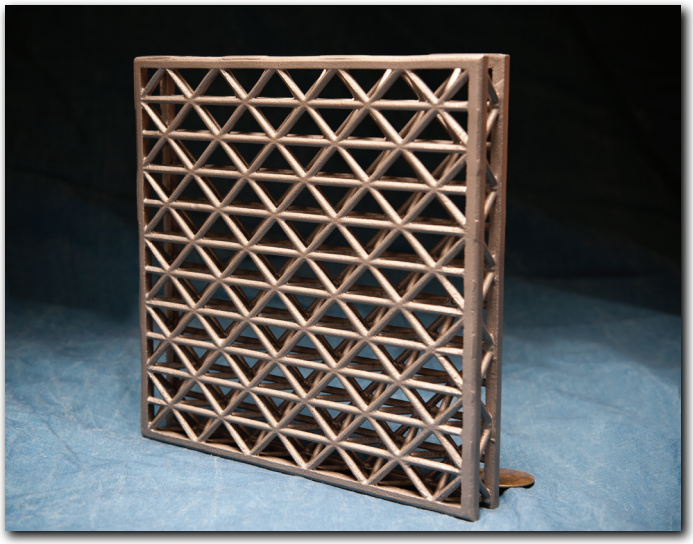
- **Versatile:** Lattice structure can be applied to any material, including aluminum, steel, nickel superalloys, fiber-reinforced composites, etc., whereas honeycomb can only be fabricated from alloys that can be rolled
- **Lightweight:** A lattice block 15- by 25-cm IN718 casting with 1.5-mm-diameter ligaments achieves 85 percent weight savings over a solid IN718 of the same dimension
- **Durable:** These materials can withstand high heat and temperature variations
- **Lattice block structure** is ductile and defect tolerant
- **Metallic foams** provide high impact resistance and excellent acoustic absorption

TECHNOLOGY DETAILS

Lattice block materials are manufactured into a lightweight truss structure similar to trusses on a highway bridge, but on a centimeter scale. The sandwich structure encases a lightweight metallic foam core, which provides structural strength and significant weight savings. The foam core decreases overall density, enhances stiffness, and increases structural and acoustic damping. The open structures permit cooling, acoustic absorption, and other multifunctional design advantages.



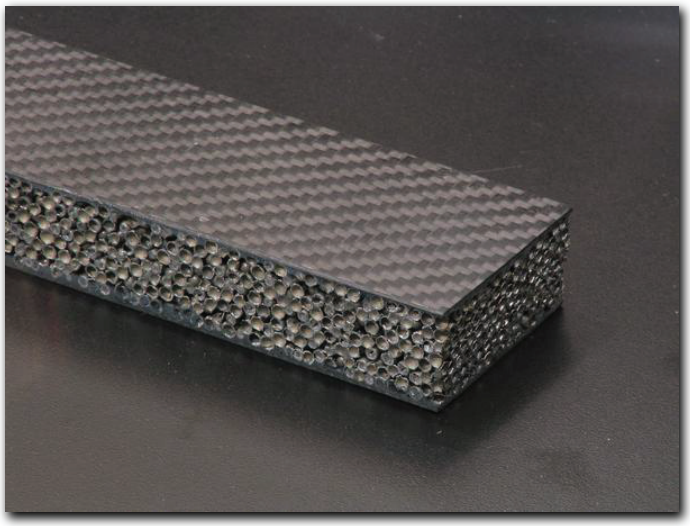




HOW IT WORKS

Lattice block materials are formed using three-dimensional printing and investment casting processes. Casting allows the part to be cast to size, avoiding the need for extensive thermomechanical processing and joining. The resulting structure is both redundant in overload and defect tolerant in fatigue.

Metallic foams are stiffer than polymer foams, extremely fire resistant, and fully recyclable (reducing their carbon footprint), and they do not generate toxic fumes at high temperatures. Because metallic foams use powder metallurgy, they are inexpensive to cast (as compared to casting of other hollow parts). Due to their intrinsic characteristics, metallic foams have high energy absorption, low thermal conductivity, and low magnetic permeability and are highly effective at noise suppression, especially in comparison to lightweight hollow parts.



WHY IT IS BETTER

Lattice block and metallic foams reduce overall weight by replacing individual structures that perform single functions. Lattice block structures significantly increase damage tolerance with low to moderate fabrication costs (depending on material type). They provide excellent strength and stiffness, with just 15 percent of the density of a similarly sized solid plate. Due to the three-dimensional printing and investment casting processes, more intricate and complex structures can be fabricated, and these exhibit significantly higher energy absorption and stiffness/strength.

In comparison to polymers that are presently being used in automobiles, metallic foams are stiffer, stronger, and more energy absorbent. These foams are also more fire resistant and more climate resistant (whereas polymers are more prone to deteriorate in ultraviolet (UV) light, humidity, and temperature extremes). Furthermore, use of metallic foams in hollow parts of the car will significantly reduce noise and strengthen a vehicle's weak points to enhance driver safety.

CAPABILITIES

Glenn Research Center is one of the leaders in testing and evaluation of structural materials as well as structural analysis tools for component design and analysis. Glenn innovators have fabricated and tested multiple lattice block patterns and metallic foam structures and honed the materials for use in aerospace and nonaerospace applications.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to partner with Glenn on lattice block and metallic foam structure materials for nonaerospace applications.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Polymer Reinforced Aerogels

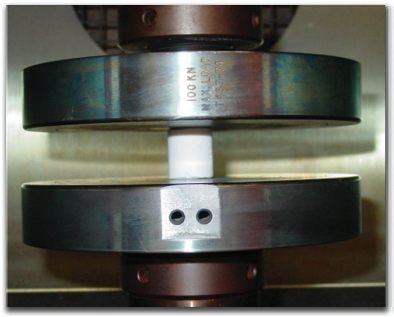
For acoustic, structural, and thermal insulation of automotive vehicles

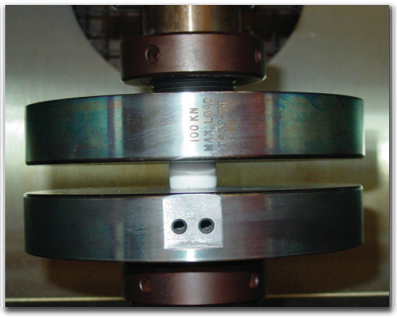
TECHNOLOGY OPPORTUNITY

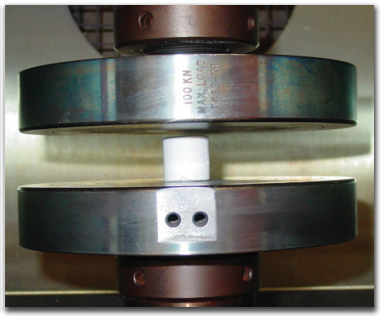
NASA's Glenn Research Center has developed a way to reinforce silica aerogels using a conformal coating of polymer to significantly enhance their strength and durability. These polymer-reinforced aerogels are lightweight, porous, and have low thermal conductivity, which makes them an ideal material for numerous automotive applications. Made from lightweight, mechanically strong materials, they can be used for acoustic and thermal insulation (e.g., engine firewall), vibration damping, or anywhere structural foam is currently used in vehicles.

BENEFITS

- **Mechanically strong:** Over 100 times stronger than conventional aerogels
- **Low thermal conductivity:** R values range from 2 to 10 times higher than polymer foams
- **Very lightweight:** Materials are up to 95 percent porous
- **Streamlined manufacturing process**

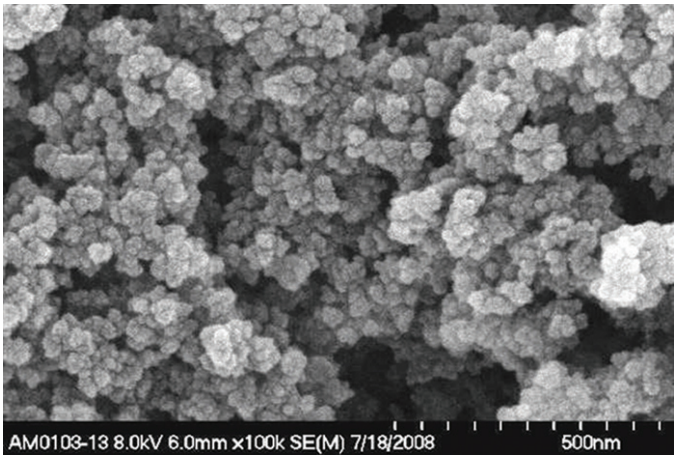






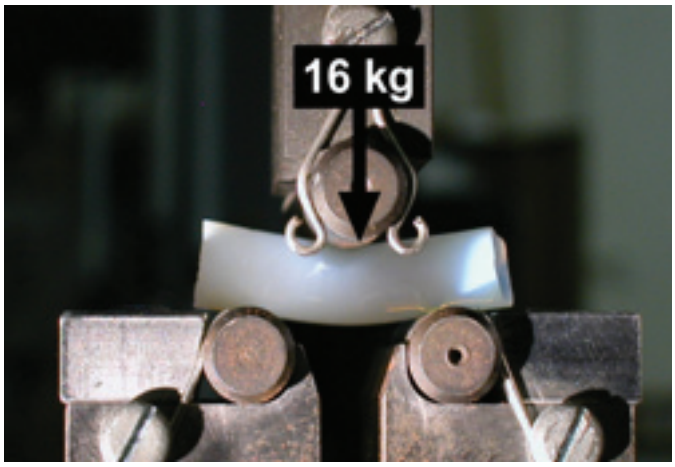
APPLICATIONS

- Thermal insulation
- Acoustic insulation for motor vehicle passenger compartments
- Vibration damping materials
- Ballistic impact absorbing materials
- Hose insulation
- Catalytic supports
- Dielectrics for fast electronics
- Optical sensor supports
- Automotive components
- Structural components in layered or sandwich-type composites



HOW IT WORKS

One of the major drawbacks of using commercially available aerogels is that they are highly fragile, prone to breaking or shedding, and sensitive to moisture. Innovators at Glenn have discovered a way to reinforce silica aerogels using a conformal polymer coating to significantly enhance their strength and durability. They have shown that incorporating a flexible alkyl or alkylene oxide chain, capped with bis(trialkoxysilyl) groups into the underlying metal oxide of polymer cross-linked aerogels provides a more resilient aerogel monolith. In the process of creating the aerogel, flexible linking groups can be included in the initial sol and co-react with tetraalkoxysilanes and other silanes used for cross-linking. The gel that forms from this process is washed and soaked in a monomer solution that reacts with the surface groups to form a conformal coating over the gel structure. Following this process, supercritical drying results in a stronger, tougher aerogel. The amounts of silica, flexible linking groups, and surface cross-links in the final monolith can be tailored to specific needs, resulting in custom density, superior toughness, and improved recovery after compression. Alternatively, certain monomers such as epoxy can be included in the sol before gelation, since they do not interfere with gelation. This one pot process reduces processing time even further.



WHY IT IS BETTER

Glenn's new approach to overcome the fragility and durability shortcomings of conventional aerogels makes them highly desirable for a variety of automotive applications. The polymer reinforced aerogels offer unprecedented durability and strength. They provide better thermal, structural, and acoustic insulation, which reduces the overall weight and bulk of the insulation needed. If the insulation is better, the manufactured product can be smaller, since the insulation does not need to be as thick. This in turn reduces manufacturing costs and other associated expenses. Unlike multilayer insulation, aerogels do not require a high vacuum to maintain their low thermal conductivity and can function as good thermal insulators at ambient pressure. In addition, they are good electrical insulators and have low refractive indices—both approaching values close to air. The polymer reinforced aerogels also are excellent vibration-damping materials. Recent work has led to the development of advanced hydrophobic formulations (important for use in damp environments), streamlined and improved safety in the manufacturing process, and greater temperature stability.

PATENTS

Glenn has a patent and patents pending on this technology (U.S. Patent No. 7,732,496).

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Polymer Reinforced Aerogels (LEW–18265–2, LEW–17685–2, LEW–18265–1, LEW– 18042–1, and LEW–17685–1).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Polyimide Aerogels

For acoustic and thermal insulation and lightweight structures for automotive vehicles and other applications

TECHNOLOGY OPPORTUNITY

NASA's Glenn Research Center has developed exceptionally strong polyimide aerogels that are up to 500 times stronger than conventional aerogels. These cross-linked polyimide aerogels are lightweight and porous, with low thermal conductivity, making them an ideal material for numerous automotive applications. They can be formed into monoliths or thin films for use in acoustic and thermal insulation (e.g., engine firewall), vibration damping, thin-film coatings, or anywhere structural foam is currently used in vehicles.

BENEFITS

- **Mechanically strong:** Up to 500 times stronger than conventional aerogels
- **Versatile:** Can be custom manufactured as monoliths and thin films
- **Low thermal conductivity:** R values range from 2 to 10 times higher than polymer foams in line with silica aerogels of the same density
- **Very lightweight:** Materials are up to 95 percent porous
- **Streamlined manufacturing process**

APPLICATIONS

- Thermal insulation
- Acoustic insulation for motor vehicle passenger compartments
- Vibration damping materials
- Ballistic impact absorbing materials
- Hose insulation
- Catalytic supports
- Dielectrics for fast electronics
- Optical sensor supports
- Automotive components
- Structural components in layered or sandwich-type composites

HOW IT WORKS

The polyimide aerogels are cross-linked through use of octa(aminophenyl)silsesquioxane (OAPS). Gels formed from polyamic acid solutions and OAPS are chemically imidized and dried using supercritical CO_2 extraction to create aerogels with densities from 0.08 to 0.2 g/cm^3. Drying the gels supercritically maintains the solid structure of the gel, creating a polyimide aerogel with improved mechanical properties over other aerogels. Notably, the polyimide aerogels cross-linked with OAPS have higher modulus than even polymer-reinforced silica aerogels of similar density and can be fabricated as both monoliths and thin films. NASA's polyimide aerogels are 85 to 95 percent porous, have high surface areas, low shrinkage, and low thermal conductivity.

WHY IT IS BETTER

Glenn's innovative polyimide aerogels are flexible, foldable, and possess very low thermal conductivity. They offer unprecedented compressive and tensile strength (up to 500 times stronger than conventional aerogels) and can withstand temperatures of 300 to 400 °C (as opposed to previous versions that reached 100 °C). Because they provide better thermal and acoustic insulation, the overall weight and bulk of the insulation is reduced. This allows for a smaller manufactured product, thus reducing manufacturing costs and other associated expenses. Unlike multilayer insulation, aerogels do not require a high vacuum to maintain their low thermal conductivity and can function as good thermal insulators at ambient pressure. The polyimide aerogels also are excellent vibration-damping materials. Recent work has led to the development of more hydrophobic formulations (important for use in damp environments) and greater temperature stability.

PATENTS

Glenn has filed a patent application for this technology.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Polyimide Aerogels With Three-Dimensional Cross-Linked Structure (LEW–18486–1).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Development and Validation of Advanced Gear and Drive Systems

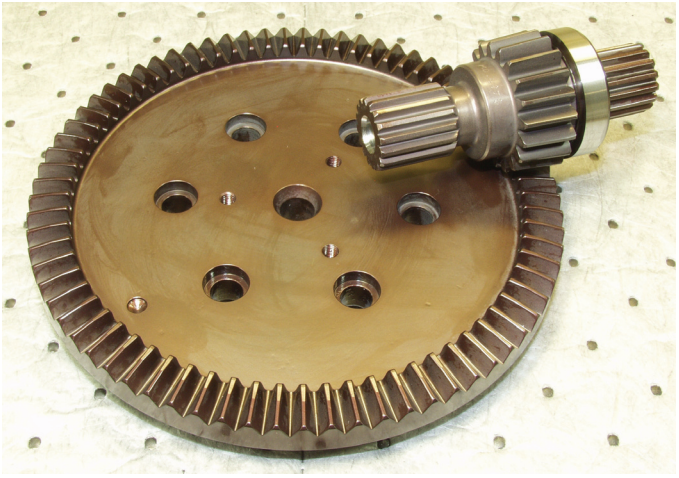
TECHNOLOGY OPPORTUNITY

Over the past 30-plus years, NASA's Glenn Research Center (GRC) has been conducting pioneering research on advanced gear and drive systems technologies. GRC's research and development of novel gear materials, lubrication formulations and applications, and super finishing technologies have helped to significantly increase the reliability and power-to-weight ratio of modern rotorcraft drive systems. GRC's expertise in these and other advanced drive system technologies combined with its unique test facilities represent a national asset that can, through partnerships, provide a competitive edge for U.S. industry.

BENEFITS

U.S. industries can leverage GRC's expertise, testing data, and state-of-the-art facilities to develop new products and enhance competitiveness in the marketplace:

- GRC expertise in advanced drive systems technologies can be leveraged for industrial applications where reduced weight and increased durability of drive systems substantially impacts product competitiveness.
- GRC gear component test facilities have over 30 years of data on the effects of gear materials, lubrication, and surface finish on gear tooth surface fatigue life.
- New test facilities have recently been added to provide experimental validation in new research areas such as high cycle gear tooth bending fatigue, gear windage losses, and vapor mist lubrication.



EXPERTISE AT GRC IN ADVANCED GEARING AND DRIVE SYSTEMS TECHNOLOGIES

Gear Fatigue

- Extensive database documenting the effects of material, lubrication, etc., on gear fatigue life

High-Speed Gear Lubrication

- Gear system thermal and windage modeling
- Advanced lubrication concepts (e.g., vapor mist and additives)

Mechanical Systems Diagnostics and Prognostics

- Gear and bearing damage detection methods
- Data fusion technology to improve reliability and reduce false alarms

Gear Fatigue Crack Modeling

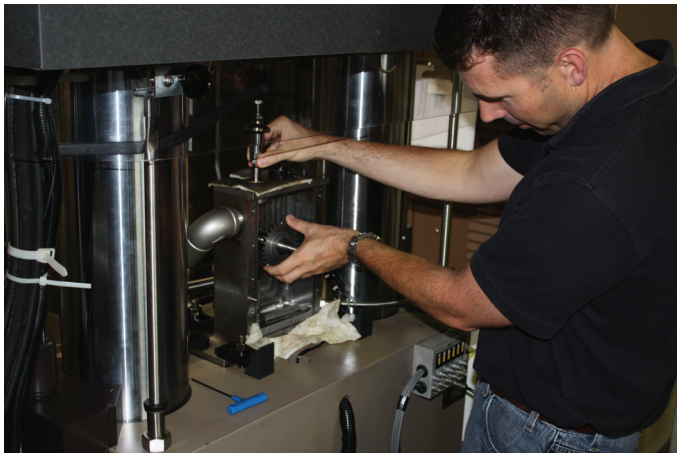
- High-fidelity, experimentally validated three-dimensional modeling of gear fatigue crack growth

Gear Geometry

- Novel gear concepts, including high pressure angle gears and face gears

Bearings

- State-of-the-art rolling element bearing analysis capabilities



EXPERIMENTAL FACILITIES AT GRC IN ADVANCED GEARING AND DRIVE SYSTEMS TECHNOLOGIES

Gear Surface Fatigue Test Facilities

- Capable of gear tooth surface durability and wear, fatigue, scoring, and dynamics testing. Four test rigs available, including two capable of testing well beyond the material and lubrication limits of current technology

Gear Bending Fatigue Test Facility

- Capable of conducting gear tooth bending fatigue tests at up to 1000 cycles per second, allowing for high cycle fatigue tests to be completed in weeks

High-Speed Helical Gear Test Facility

- Capable of conducting high-speed gear lubrication and oil research

Gear Windage Test Facility

- Capable of conducting high-speed gear windage tests at pitch line velocities of up to 55,000 ft per minute

Gear Noise and Dynamics Test Facility

- Capable of isolating and measuring vibration and noise of test gear mesh in a semi-anechoic chamber environment

Bevel Gear Test Facilities

- Capable of testing durability and dynamics of right angle gear drives, including bevel gears and newly developed face gears

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA Glenn offers partnership opportunities for the development and validation of advanced gear and drive systems.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Shape Memory Alloys

TECHNOLOGY OPPORTUNITY

NASA's Glenn Research Center invites companies to establish partnerships to investigate potential applications for Shape Memory Alloys (SMAs). SMAs are materials that can be deformed at low temperature and recover their original shape upon heating. Glenn Research Center has been working to develop new alloys that can operate up to ~300 °C, compared to ~80 °C of commercially available alloys. In addition, NASA has been working on supporting technologies (modeling tools, design methodologies, test standards, material supply chain, etc.) that will promote the application of shape memory alloys for adaptive structures and actuators.

BENEFITS

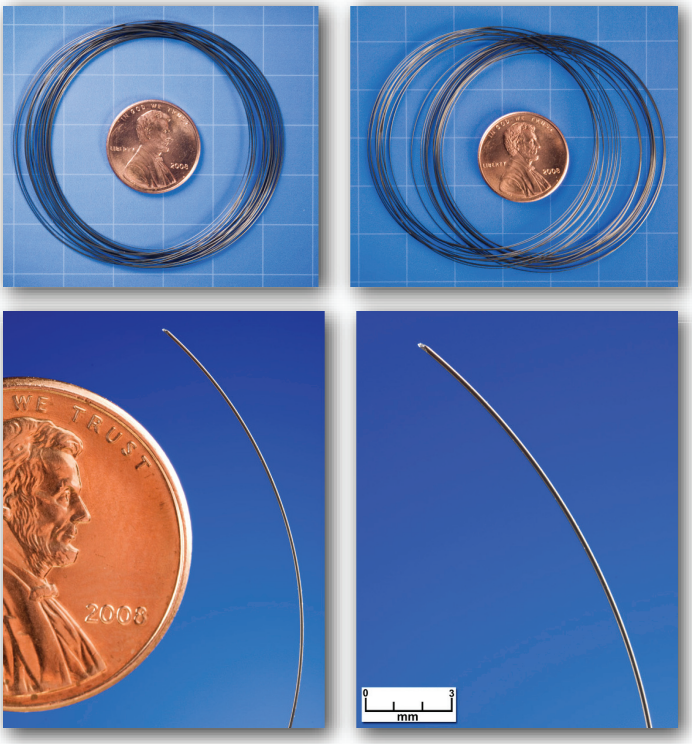
- Provide high force (per volume/weight) allowing lightweight compact actuator designs
- Eliminates extraneous systems (hydraulic, pneumatic, etc.)
- Passive control (responds to temperature change), which eliminates the need for sensors and electronics
- Simple frictionless designs result in less maintenance

TECHNOLOGY DETAILS

SMAs are alloys that have memory. The materials are deformed at low temperature and recover to their original shape upon heating. Applications of SMAs have been limited due to their low transformation temperatures. Glenn has been working to develop new high transformation temperature SMAs and as a result has developed a suite of high work output SMAs as well as design application tools and expertise.

HOW IT WORKS

SMAs can be used in passive, active, or superelastic design applications. Passive design applications result from the material heating during normal operation resulting in an actuation force. Active design applications use the material below its transformation temperature and use of supplemental heat to provide an "on-demand" actuation force. Superelastic design applications use the material above its transformation temperature and transforms due to stress.



WHY IT IS BETTER

SMAs are ideal for high force, large stroke, and modest frequency response operations. One example application currently being developed has an SMA to replace a traditional motor/gearbox actuation system at significant weight savings (41:1).

PATENTS

LEW–16685–1, U.S. Patent No. 6,151,897
LEW–16685–2, U.S. Patent No. 6,367,250
LEW–18054–1, U.S. Patent No. 7,501,032

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Shape Memory Alloys.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

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National Aeronautics and
Space Administration

Advanced Hydrogen and Hydrocarbon Sensors

For in situ leak detection, emissions monitoring, and pressure measurements

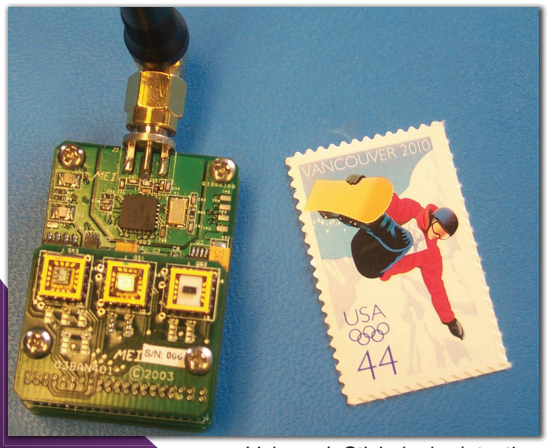
TECHNOLOGY OPPORTUNITY

Innovators at NASA's Glenn Research Center have developed advanced hydrogen and hydrocarbon gas sensors capable of detecting leaks, monitoring emissions, and providing in situ measurements of gas composition and pressure. These compact, rugged sensors can be used to optimize combustion and lower emissions and are designed to withstand harsh, high-temperature environments (e.g., silicon carbide (SiC) sensors can operate at 600 °C). NASA Glenn is actively seeking industrial partners to cooperatively develop and apply these cutting-edge sensor systems in new applications.

BENEFITS

- **Rugged:** Functions in environments where conventional sensor systems are inoperable
- **Low cost:** Emissions sensors can replace more expensive gas measurements systems; high-temperature SiC pressure sensors can eliminate the need for cooling
- **Versatile:** Can be used in a range of configurations, including wireless and "Lick and Stick" sensor systems
- **Responsive:** High-temperature SiC pressure sensor enables high-frequency pressure measurements in combustion environments
- **Easy to install:** Lick and Stick leak detection system can be applied wherever safety information is needed

SiC pressure sensor and pressure response of sensor at temperatures as high as 610 °C (following 1100 hr of high-temperature testing).



Lick and Stick leak detection system provides self calibration and ready installation.

APPLICATIONS

- Leak detection for hydrogen-powered vehicles
- Rapid inspection of valve and seal integrity
- Storage tank headspace monitoring
- System health monitoring
- Engine emissions monitoring and control
- Industrial process monitoring
- Safety monitoring
- Alarms for high-temperature pressure vessels and piping
- Fire detection and environmental monitoring
- High-frequency pressure measurements in combustion environments, for example, in-cylinder pressure measurements

TECHNOLOGY DETAILS

NASA Glenn Research Center, in conjunction with academia and industry, has developed a range of microelectromechanical systems (MEMS)-based and SiC-based microsensor technologies that are well suited for automotive applications. The suite of technologies includes (1) hydrogen and leak detection sensors; (2) emissions sensor arrays; and (3) SiC high-temperature pressure sensors.

The hydrogen and leak detection sensors are currently being used to protect astronauts on the International Space Station, and they have many Earth-based applications as well. They can function as a single-sensor unit or form part of a complete "smart" sensor system that includes multiple sensors, signal conditioning, power, and telemetry. Sensors for hydrocarbons (such as methane), oxygen, temperature, and pressure can be included in the array.

The emissions sensor array have high sensitivity and stability and provide gas detection at temperatures ranging from at least 450 to 600 °C. The gas sensing structure detects various combustion emission species (carbon monoxide, carbon dioxide, oxygen, hydrocarbons, and nitrogen oxides) over a wide range of concentrations.

The SiC high-temperature pressure sensor can operate at temperatures as high as 600 °C, whereas standard pressure sensors are temperature-limited. This sensor has been successfully used in NASA combustion rigs to detect combustion instabilities. It is well suited for in-cylinder pressure measurements for automotive engines.

Enabling new capabilities: Hydrogen sensor utilization for leak detection in assembly of a natural-gas-powered vehicle.

WHY IT IS BETTER

NASA's sensors are small, smart, and versatile systems with the reliability to enable new functionality in a range of applications. These advanced sensors operate in situ and are designed to withstand harsh, high-temperature environments where many conventional sensors cannot operate. The primary applications include leak detection, emissions monitoring, and combustion process monitoring, but the technologies can also be used in chemical processing monitoring and environmental monitoring and to enhance safety.

PATENTS

1. MEMS direct chip attach packaging methodologies and apparatuses for harsh environments, U.S. Patent 7,518,234, April 14, 2009.
2. MEMS direct chip attach packaging methodologies and apparatuses for harsh environments, Patent 6,845,664, January 25, 2005.
3. Miniaturized metal (metal alloy)/PdO.x/SiC hydrogen and hydrocarbon gas sensors, U.S. Patent 7,389,675, June 24, 2008; and U.S. Patent 8,001,828, August 23, 2011.
4. Gas sensors using SiC semiconductors and method of fabrication thereof, Patent 6,763,699, July 20, 2004.
5. Gas sensing diode comprising SiC, U.S. Patent 6,291,838, September 18, 2001.
6. Gas sensing diode and method of manufacturing, U.S. Patent 6,027,954, February 22, 2000.
7. Method and apparatus for the detection of hydrogen using a metal alloy, U.S. Patent 5,668,301, September 16, 1997.
8. PDTI metal alloy as a hydrogen or hydrocarbon sensitive metal, U.S. Patent 5,520,753, May 28, 1996.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the above patents and the following technologies:

1. Processing of Nanostructured Devices using Microfabrication Techniques, LEW–18492–1
2. Carbon dioxide gas sensors and method of manufacturing and using same, LEW–17916–1

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Fiber-Reinforced Foam (FRF) Core Sandwich Composite Structures

Strong and lightweight materials with improved strength, stiffness, and damage resistance

TECHNOLOGY OPPORTUNITY

NASA's Glenn Research Center invites companies to establish partnerships to explore applications for its novel FRF Composite Structures. FRF sandwich composites offer significant weight savings over traditional metal components, and they can easily be manufactured to meet specific functional requirements. The composites can withstand severe impact caused by fragments or debris and are ideally suited for use in dynamic loads.

BENEFITS

- **Versatile:** Technology allows for multifunctional design possibilities (structural strength and noise attenuation)
- **Lightweight:** 30 to 40 percent lighter than traditional metal parts
- **Rugged:** Environmentally durable material
- **Efficient:** Same energy absorption as metallic structures but at half the weight

TECHNOLOGY DETAILS

These manufacturing processes and design tools were originally developed by NASA for use in safety-critical aerospace components with severe impact and dynamic load requirements (i.e., jet engine fan casing/fan blade failure containment system). Glenn Research Center has developed structural analysis and sizing optimization tools for the fabrication of components that are strong, lightweight, durable, and impact resistant.

HOW IT WORKS

These engineered core composite sandwich structures are made from foam and structural fibers (e.g., glass or carbon) using fiber placement and resin infusion molding processes. The process has been adapted to allow the FRF cores to be produced in (1) a continuous sheet roll (sheet core process) for panels or (2) a continuous snake (snake core process) for cylindrical components such as fan containment casings. These “spoolable” core forms enable more streamlined and automated manufacturing of unitized or monocoque structures.

WHY IT IS BETTER

FRF sandwich composites are an improvement over standard composite fluted structures due to their ability to be customized for various engineering applications. The materials used, as well as the structural design of the FRF sandwich composite, can be tailored to suit unique applications. Simple changes to the foam material will alter the characteristics of the final product to improve impact resistance, acoustic absorption, vibration damping, and thermal insulation. Changes to the structural design can result in structural improvements (e.g., lighter weight) without sacrificing structural integrity.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn’s Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider partnering in the application of Fiber-Reinforced Foam Sandwich Composite technology (LEW–18527–1 and LEW–18528–1).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

High-Temperature, Low-Melt Resins for Liquid Molding

Fabricating resin transfer molding (RTM) composites with zero emissions

TECHNOLOGY OPPORTUNITY

NASA's Glenn Research Center invites companies to license or establish partnerships to develop its patented high-temperature, low-melt imide resins for fabrication of automotive components. Produced by a solvent-free melt process, these resins exhibit high glass transition temperatures (T_g = 370 to 400 °C), low-melt viscosities (10 to 30 poise), long pot-life (1 to 2 hr), and can be easily processed by low-cost RTM and vacuum-assisted resin transfer molding (VARTM). These RTM resins melt at 260 to 280 °C and can be cured at 340 to 370 °C in 2 hr, without releasing any harmful volatile compounds.

BENEFITS

- **Clean and green technology:** Solvent-free melt process produces zero emissions
- **Easy to adopt:** Compatible with current manufacturing techniques
- **Longer pot life:** 1 to 2 hr
- **Long shelf life:** Resins do not deteriorate over time at ambient temperatures
- **Suitable for high-temperature applications:** Performs above 300 °C, exceeding conventional RTM resins such as epoxy and bismaleimides, which have use temperatures around 177 and 232 °C, respectively
- **Efficient:** Enables direct net shape production from monomers by injection molding and resin transfer molding to afford final products
- **Low maintenance:** Self-lubricating when chopped carbon fibers are added
- **Lightweight:** Provides up to 20 percent in weight savings over metallic components
- **Improved safety:** Eliminates the need for hazardous organic solvents
- **High quality:** Solvent-free melt process yields a more consistent product and lowers the danger of contamination in the final resin product
- **Cost effective:** Production of a low-melt viscosity polyimide resin using a solvent-free melt process reduces the cost of manufacturing

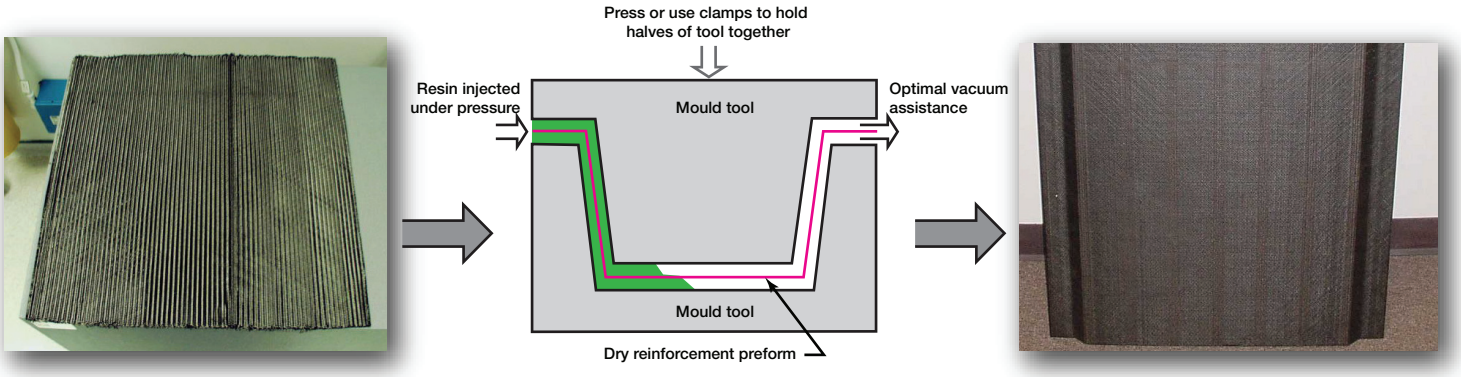
APPLICATIONS

- Injection molding for trim, structural support plastics, gears, etc.
- High-temperature engine components; for example, bushings and bearings
- Selective laser sintering for prototypes
- Composite ducts and tubes
- Self-lubricating parts with chopped fibers

Fabrication Methods:
- RTM and VARTM

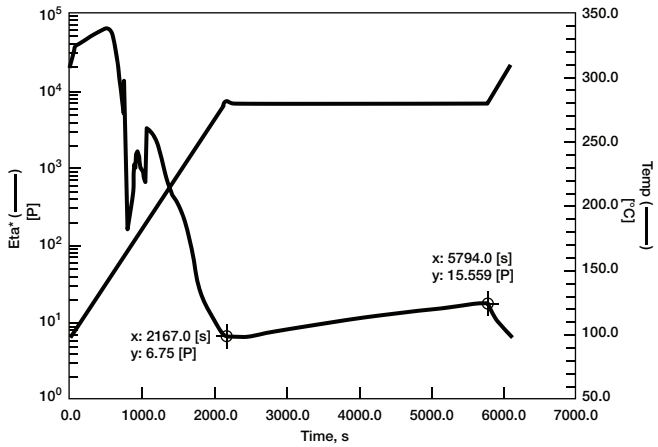
TECHNOLOGY DETAILS

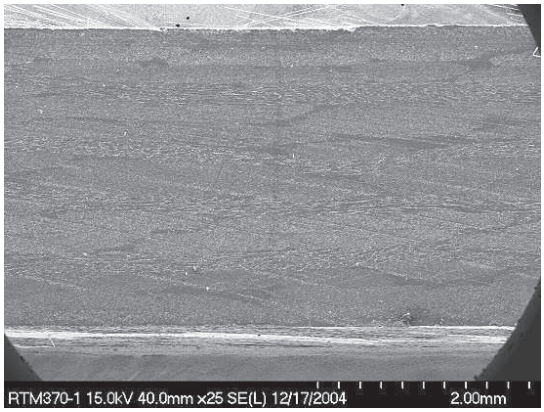
This technology was developed to make polyimide resins from novel asymmetric dianhydrides (a-dianhydrides) and kinked diamines to achieve low-melt viscosities that are amenable to low-cost RTM and VARTM, while retaining high-temperature finished product performance above 300 °C. These a-dianhydride-based RTM imide resins display low-melt viscosities (10 to 30 poise), which cannot be achieved using normal symmetric dianhydrides.



HOW IT WORKS

RTM imide resins can be melted at 260 to 280 °C, and injected into fiber preforms under pressure (200 psi) or vacuum (VARTM). The resins also can be made into powder prepregs with lengthy out-time by melting the resin powders so that they fuse onto fibers.





WHY IT IS BETTER

RTM imide resins display high softening temperatures (370 to 400 °C) and excellent toughness, as evidenced by the RTM370 resin's open-hole compression strength. The resins also possess significant thermo-oxidative stability by long-term isothermal aging at 288 °C (550 °F) for 1000 hr. The unique melt process without a solvent provides a manufacturing advantage over the expensive high boiling solvents previously needed to produce oligomers. This process also eliminates the need for tedious and high-cost solvent removal.

PATENTS

Glenn has patented this technology (U.S. Patent No. 7,015,304).

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Solvent-Free Low-Melt Viscosity Imide Resins (LEW–17618–1).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Lightweight Fiber-Optic Sensors for Real-Time Strain Monitoring

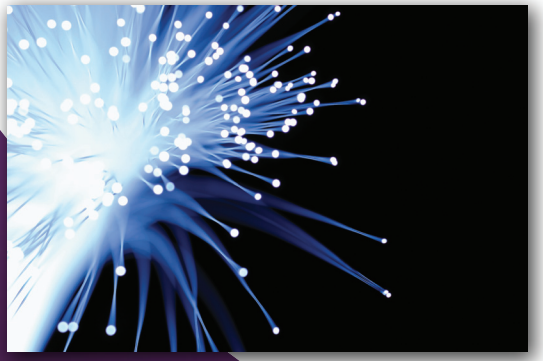
To improve efficiency and safety in aerospace, civil engineering, transportation, oil and gas, renewable energy, and medicine

TECHNOLOGY OPPORTUNITY

Innovators at NASA's Dryden Flight Research Center have developed a lightweight, robust fiber-optic sensor system that represents a major breakthrough in sensing technology. The sensors, along with NASA's sophisticated algorithms, can be used to calculate a variety of critical parameters, including shape, stress, temperature, pressure, strength, and operational load. This state-of-the-art sensor system is small, lightweight, easy to install, and fast—it processes information at rates of 100 times per second. For the first time ever, real-time strain measurements can be used to determine the shape of an aircraft's wing, monitor the structural integrity of bridges and pipelines, or ensure precise placement of the tiniest catheters, to name just a few potential applications.

BENEFITS

- **High resolution:** Thousands of sensors can be placed at half-inch intervals for more comprehensive imaging than previously possible
- **Fast:** Provides a 100-Hz refresh rate to enable real-time strain monitoring
- **Small and lightweight:** Uses virtually weightless sensors and hardware the size of a shoebox
- **Comprehensive data:** Calculates shape, stress, temperature, pressure, strength, and operational load
- **Nonintrusive:** Uses a monitoring fiber that does not affect performance
- **Easy to install:** Installs more quickly than conventional strain gauges and in regions previously inaccessible
- **Robust:** Resists radiation and electromagnetic/radiofrequency interference



APPLICATIONS

- **Aerospace:** Sensing shape, structural health monitoring
- **Medical:** Monitoring medical robotics, catheters, magnetic resonance imaging (MRI) machines, and radioactive environments
- **Renewable wind energy:** Monitoring wind turbine blade deformation
- **Civil structures:** Designing and monitoring bridges, tunnels, buildings, and dams
- **Automotive:** Monitoring frame stress for improved safety and performance
- **Transportation and rail:** Monitoring integrity of train and tracks
- **Marine:** Monitoring oil tankers, navy vessels, competitive yachts, and submarine hulls
- **Oil and gas:** Detecting leaks, monitoring pipelines, and downhole drilling
- **Power:** Monitoring nuclear power plant vibration and temperature
- **Seismology:** Monitoring shifts in the Earth's crust
- **Mining:** Monitoring integrity of shafts
- **Military:** Detecting chemical or biological agents

HOW IT WORKS

The technology employs ultraefficient, real-time, and data-driven algorithms for interpreting strain data. The fiber Bragg grating (FBG) sensors respond to strain due to stress or pressure on the substrate. The fiber may also be covered with a “smart coating” that detects strain based on temperature, the presence of chemicals, and other factors. The sensors feed these strain measurements into the system's algorithms to determine shape, stress, temperature, pressure, strength, and operational load in real time.

WHY IT IS BETTER

Conventional strain gauges are heavy, bulky, spaced at distant intervals (which leads to lower resolution imaging), and unable to provide real-time measurements. Dryden’s system is virtually weightless, and hundreds of sensors can be placed at half-inch intervals along an optical fiber the size of a human hair. Because these sensors can be placed at such close intervals and in previously inaccessible regions (e.g., within bolted joints and embedded in a composite structure), the high-resolution strain measurements are much more precise than ever before. The fiber optic sensors are nonintrusive and easy to install—thousands of sensors can be installed in less time than conventional strain sensors—and the system is capable of processing information at the unprecedented rate of 100 samples per second. This critical, real-time monitoring capability enables an immediate and informed response in the event of an emergency and allows for precise, controlled monitoring to help avoid such scenarios.

PATENTS

Dryden has two patents issued (U.S. Patent No. 7,520,176 and U.S. Patent No. 7,715,994), and two others are pending for this technology.

LICENSING AND PARTNERING OPPORTUNITIES

This technology is part of NASA's Innovative Partnerships Program that seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider partnering with NASA or licensing this Intrinsic Fiber Optic Sensor Portfolio (DRC–006–024, DRC–008–023, DRC–006–045, DRC–007–001, and DRC–009–013) for commercial applications.

FOR MORE INFORMATION

Julie Holland
PO Box 273, MS 1100
NASA’s Dryden Flight Research Center
Edwards, CA 93523–0273
Phone: 661–276–2515
E-mail: julie.a.holland@nasa.gov

National Aeronautics and
Space Administration

Fluid Measurement Sensor

A wireless, powerless, passive inductor-capacitor sensor for measuring fluid level, pitch and roll angles, and volume

TECHNOLOGY OPPORTUNITY

NASA Langley researchers have developed a wireless, thin-film fluid measurement sensor that uses a magnetic field response measurement acquisition system to provide power to the sensor and to acquire physical property measurements from it. SansEC (sans electrical connections) is a brand new system for sensing various physical quantities. It is a unique framework for designing, powering, interrogating, and manufacturing passive electrical sensors using only a single electrical component. In addition to measuring fluids within an enclosed container, it can be placed external to a non-conductive container to measure the level of any non-gaseous substance, including liquids, solids, and semi-solids such as powder or granular substances.

BENEFITS

- Receives power wirelessly, eliminating the need for a sensor power source
- Sends signals wirelessly to the data acquisition device, eliminating signal wiring
- Reduces system weight due to less wiring
- Non-mechanical method for fluid measurement – no moving parts, reducing the probability of failure
- Eliminates potential for arcing (safer use in fuel tanks)
- Lightweight
- Can measure fuels without opening the tank, reducing emission of harmful gases

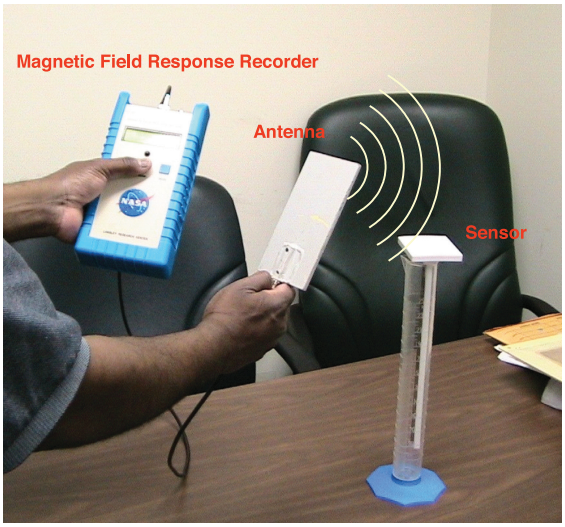
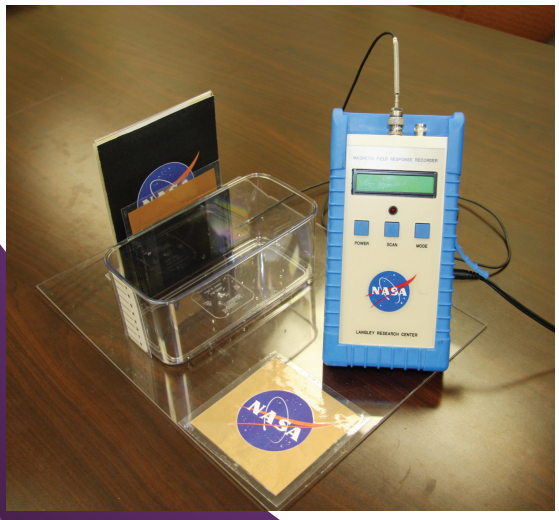


Figure 1: The Magnetic Field Response Recorder (the handheld magnetic field response measurement acquisition unit) emits a magnetic field harmonic at the lowest frequency in the sensors frequency range. The frequency range corresponds to a physical state's measurement range. For example, 5–6 MHz could correspond to 0–20 cm of a fluid level.



COMMERCIAL APPLICATIONS

The technology offers wide-ranging market applications, including:

- Fuel and other liquid measurements in vehicles
- Above or below ground fuel storage tanks
- Cryogenic fluid tanks

TECHNOLOGY DESCRIPTION

The fluid measurement sensor is configured with a spiral electrical trace on flexible substrate. The sensor receives a signal from the accompanying magnetic field data acquisition system. Once electrically active, the sensor produces its own harmonic magnetic field as the inductor stores and releases magnetic energy. The antenna of the measurement acquisition system is switched from transmitting to receiving mode to acquire the magnetic-field response of the sensor. The magnetic-field response attributes of frequency, amplitude, and bandwidth of the inductor correspond to the physical property states measured by the sensor. The received response is correlated to calibrated data to determine the physical property measurement. When multiple sensors are inductively coupled, the data acquisition system only needs to activate and read one sensor to obtain measurement data from all of them.

Fluid level measurement occurs in several ways. In the immersion method, the capacitance of the sensor circuit changes as it is immersed in fluid, thus changing the frequency response as the fluid level rises or falls. Fluid level can also be measured from the outside of a non-conductive container. The response frequency from the sensor is dependent upon the inductance of the container plus the combination of fluid and air inside it, which corresponds to the level of liquid inside the container. Roll and pitch are measured by using three or more sensors in a container. With any given orientation, each sensor will detect a different fluid level, thus providing the basis for calculating the fluid angle. Volume can be measured in the same way, using the angle levels detected by the sensors and the geometric characteristics of the container to perform the volume calculation.

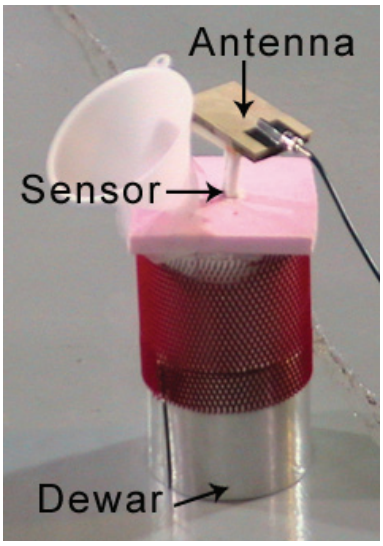


Figure 2: Magnetic field response fluid-level sensor immersed in liquid nitrogen

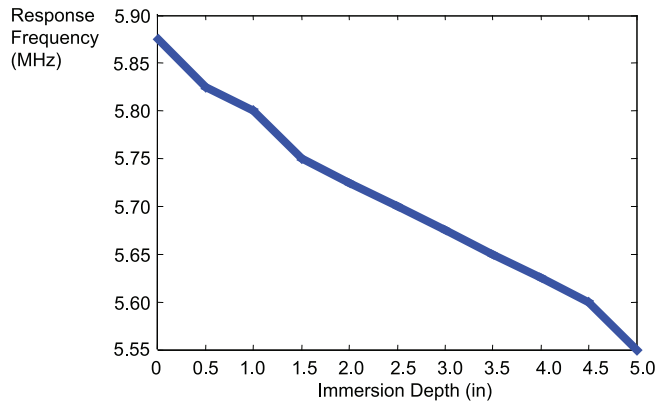


Figure 3: Measurement of cryogen level (LN2)using wireless fluid-level sensor

PATENTS

The fluid measurement sensor technology includes U.S. patent application 20070157718 and U.S. patent 7,255,004.

FOR MORE INFORMATION

If your company is interested in licensing or joint development opportunities associated with this technology, or if you would like additional information on partnering with NASA, please contact:

The Technology Gateway

National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
Hampton, VA 23681
757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
technologygateway.nasa.gov
www.nasa.gov

LAR-17480-1, LAR-17488-1, LAR-17155-1, LAR-17116-1

National Aeronautics and
Space Administration

High Temperature Liquid Crystal Thermosets

New polymer chemistries benefit processing and performance

TECHNOLOGY OPPORTUNITY

NASA Langley has a family of chemistries and supporting patents related to a series of liquid crystalline materials that have several distinct advantages over currently available commercial liquid crystalline polymers (LCPs). The NASA materials use low-melting, all-aromatic ester-based liquid crystal oligomers end-capped with reactive phenylethynyl end groups. This reactive oligomer approach enables synthesis of liquid crystal thermosets with outstanding mechanical and thermal properties that are superior to well-known high-performance polymers such as PPS and PEEK. NASA's chemistries offer inexpensive and adaptable materials for melt processing complex shapes using resin transfer molding or resin film infusion techniques. The low coefficient of expansion, combined with excellent barrier properties, makes this new technology useful for cryogenic applications and other applications that involve extreme temperature changes. In addition, the excellent barrier properties make these materials chemically resistant to acids, bleaches, chlorinated solvents, alcohols, and hydrocarbon fuels.

BENEFITS

- A much broader process window than typical LCPs. End groups are stable in the melt up to 300°C (1 hour), which gives ample time for processing
- Inexpensive—uses commercially available monomers and standard melt polymerization techniques
- Improved mechanical properties and thermal stability (Tg>250°C, Tdec~500°C)
  - Final product remains in its liquid crystalline state after curing, which enables improved chemical resistance and excellent barrier properties to small molecules
  - The low CTE and amorphous nature will allow for the fabrication of thick structures without internal stresses
  - Low melt viscosity (as low as 7 poise at 100 rad.s^{-1})
  - Low dielectric constant
- Flame retardancy and low smoke generation – these resins typically have a UL94 VO rating
- Good adhesive properties—optimum lap-shear and Tg is 5,000 to 9,000 g.mol^{-1}

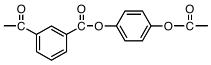
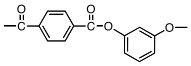
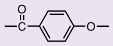
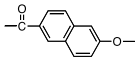
PATENTS

U.S. Patents 7,507,784 and 6,939,940, which are both titled "Liquid Crystalline Thermosets from Ester, Ester-Imide, and Ester-Amide"

COMMERCIAL APPLICATIONS

The technology offers wide-ranging market applications, including:

- Electronics – precision parts including connectors, integrated circuits, circuit breakers, sockets, minibobbins, fuse holders
- High-performance materials
  - high strength fibers for applications like tire cord
  - high strength films for applications like packaging
  - coatings, foams, and composites for applications such as:
    - vessels and piping that require solvent resistivity for chemical processing
    - replacing stainless steel in surgical instruments and sterilization trays
    - o-rings, gaskets, foam-in-place sealants, and high-performance adhesives
    - parts, panels, fans, heat exchangers, rocker covers, fuel tanks that require textile reinforced composite materials for use in aeronautic and automotive markets

Thermal Properties							
Sample	**T_m(°C)**	T_d(°C) N_2/Air	**Char Yield (wt %)**	**E' (GPa) at (25°C)**	**E' (GPa) at (200°C)**	Tg (°C)	
TA/HQ/**IA**(25)-5K	340*	486/458	51	–	–	–	
TA/HQ/**IA(**50)-5K	315	470/451	52	4.2	1.2	220	
TA/HQ/**IA(**75)-5K	321	468/457	58	3.2	1.1	243	
TA/HQ/**RS(**50)-5K	316	469/459	56	4.9	1.5	259	
TA/HQ/**HBA(**50)-5K	328	486/475	50	3.2	1.8	225	
TA/HQ/**HNA(**25)-5K	290	490/478	52	3.9	0.7	186	

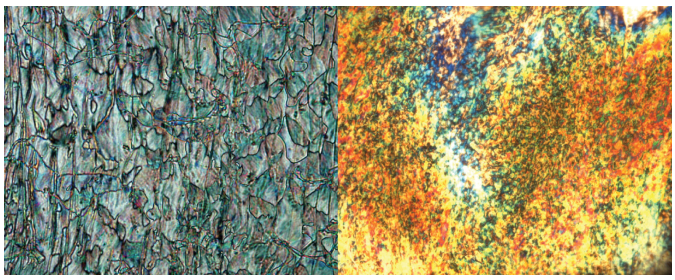
Mechanical Properties of Thin Films	Tg (°C)	E' (GPa) at 24°C	Tensile strength (MPa) at 24°C	Elongation at break (%) at 24°C
HBA/HQ/IA-9K cured at 340°C	206	7.1	69	3
HBA/HQ/IA-9K cured at 370°C	184	3.9	83	10
HBA/HQ/IA-9K cured at 400°C	175	3.3	64	2

Carbon Fiber Composite Properties 40x40 cm, 6 ply (60/40) T300 5H satin weave All-aromatic HBA/HQ/IA(32)-9k	LCT Tg = 180°C	PPS* Tg = 95°C	CETEX PEI* Tg = 210°C
Tensile strength (MPa)	671	592	656
Flexural Modulus (GPa)	51	60	50
In-plane shear strength (MPa)	154	119	118
In-plane shear modulus (GPa)	3.7	4.0	3.4

* Data as provided by Ten Cate, room temperature data only

TECHNOLOGY DESCRIPTION

Depending on the backbone chemistry and the molecular weight (controlled by reactive end group concentration), NASA has developed various liquid crystalline resins (LCRs) with a wide range of physical and chemical properties. Low concentrations of reactive end groups (e.g., a 9000 g.mol-1 oligomer) give a low viscous thermotropic melt (10–200 poise at 100 rad.s-1). When cured, a high Tg (>200°C) nematic thermoset is obtained that provides an excellent combination of toughness and stiffness.



Representative Micrographs (Polarizing Optical Image). Left image: Microphotograph, LCR-1k 370°C melt, (20x) Low viscous nematic threaded Schlieren texture. Right image: Microphotograph, LCR-1k cross-linked 1 h. 370°C, (20x) nematic thermoset

FOR MORE INFORMATION

If your company is interested in licensing or joint development opportunities associated with this technology, or if you would like additional information on partnering with NASA, please contact:

The Technology Gateway

National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
Hampton, VA 23681
757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
technologygateway.nasa.gov
www.nasa.gov

LAR-15205-2, LAR-15205-1, LAR-15941-1

National Aeronautics and
Space Administration

High-Performance Polyimide Insulation Technologies

Improved fire resistance from low-density foams

TECHNOLOGY OPPORTUNITY

Langley Research Center has developed a family of foams based on more than 25 innovative polyimide chemistries. The technology can take the form of foam or microspheres that can be used as additives. Langley refers to this technology, and associated international patents, as TEEK. The strong, low-density foam can be processed into neat or syntactic foams, foam-filled honeycomb, or other shapes, while offering excellent thermal and acoustic insulation and high-performance structural support. NASA has successfully licensed this technology, which has been used in naval vessels, and continues to offer non-exclusive licenses. Applications for the automotive industry include inflammable encasements for engines and muffler systems for sound compression.

BENEFITS

- Low thermal conductivity from cryogenic to elevated temperatures (see Figure 1)
- Flame (NHB 8060.1), chemical, solvent, and hot water resistant
- Low density ~0.008 g/cc (ASTM D-3574 [A])
- Highly resilient and durable with high compressive and tensile strength (see Figure 2)
- Low coefficient of thermal expansion (mm/mm-K at 24°C – 0.64 x e-5 to 0.89 x e-5)
- High glass transition temperature (DSC) – 237°C to 321°C
- Low dielectric constant – 1.026 to 2.125
- Hydrolytic stability and limiting oxygen index (42% to 51%)
- Ability to foam in place during installation and repair
- Nontoxic and nonfuming

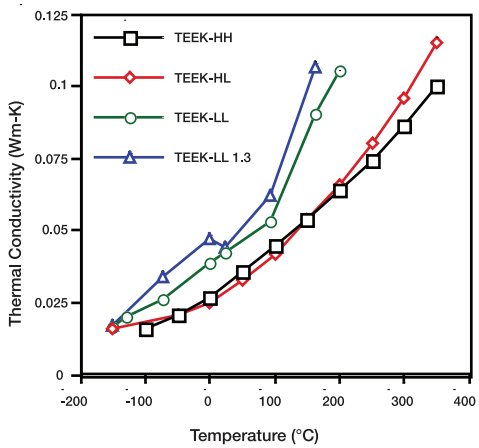
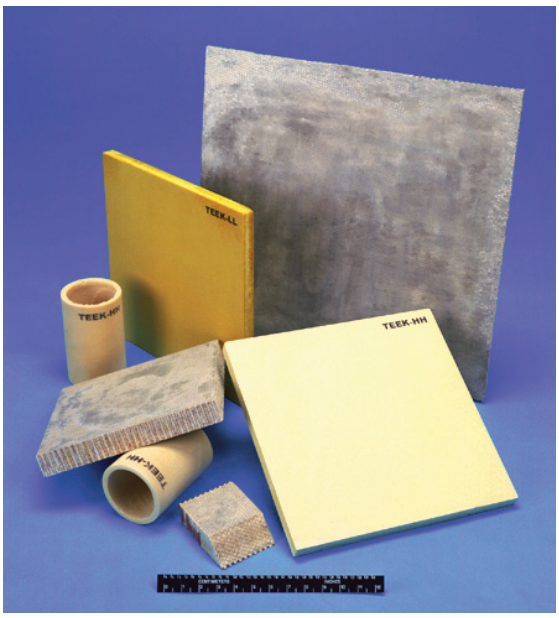


Figure 1: Thermal conductivity data for varied formulations/densities



COMMERCIAL APPLICATIONS

The technology offers wide-ranging market applications, including:

- Transportation – aerospace, aircraft, marine, automotive
- Industrial
- Construction
- Fire-resistant materials
- Improved insulation
- Soundproofing materials
- Honeycomb core replacement and filler
- Vibration damping pads
- Ablative components
- Abradable seals
- Water penetration barriers
- Radomes

TECHNOLOGY DESCRIPTION

NASA Langley developed the polyimide foam technology to meet an aerospace industry demand for high-performance structural foam with increased stiffness but without large weight increases that could operate over a large temperature regime -253°C to 232°C. The process for this foam begins with a monomeric solution with salt-like properties to yield a homogenous polyimide precursor solid residuum. The resulting precursor can be processed into polyimide neat or syntactic foams, microspheres, and filled structures like honeycomb. Each form enables production of useful articles through normal foaming techniques. Foam production is based on reacting a derivative of a dianhydride (e.g., ODPA, BTDA, PMDA) with a diamine (e.g., ODA, PDA, DDS). Foams can be fabricated to densities from 0.008 g/cc to 0.32 g/cc. Microspheres can be produced with diameters ranging from 100–1,500 microns. These microspheres can be used for foam-in-place applications or as additives to make less expensive materials more fire resistant.

NASA's foam technologies received these awards:

- 2003 Turning Goals into Reality award for Technology Innovation jointly with Kennedy Space Center, Lockheed Martin Michoud Space Systems, Boeing Huntington Beach, RTI, and Sordal.
- 2002 NASA LaRC Richard T. Whitcomb Award for Aerospace Technology Transfer
- 2001 R&D 100 Award

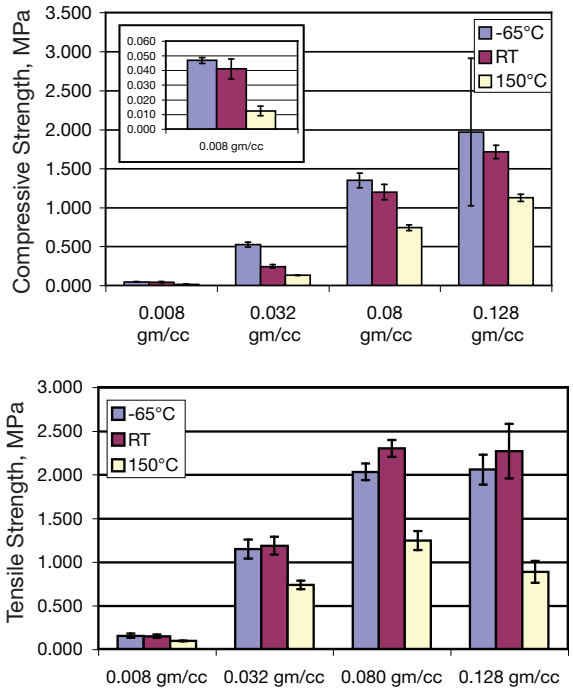


Figure 2: Compressive strength of TEEK-L foams (top) and flatwise tensile strength of TEEK-L foams (bottom). Tests performed by LaRC and Clark Atlanta University.

PATENTS

Relevant base patents:

- Aromatic Polyimide Foams, U.S. 6,133,330, Oct. 17, 2000; Japan JP3337695; EU Application 99928334.4
- Hollow Polyimide Microspheres, U.S. 5,994,418, Nov. 30, 1999; 6,084,000, July 4, 2000; U.S. 6,235,803, May 22, 2001; Japan JP3334890; EU Application 99935281.8
- Polyimide Precursor Solid Residuum, U.S. 6,180,746, Jan. 30, 2001; Japan JP3485936
- Films, Preimpregnated Tapes and Composites Made From Polyimide "Salt-Like" Solutions, U.S. 6,222,007, April 24, 2001; Japanese Application 11-557222

FOR MORE INFORMATION

If your company is interested in licensing or joint development opportunities associated with this technology, or if you would like additional information on partnering with NASA, please contact:

The Technology Gateway

National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
Hampton, VA 23681
757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
technologygateway.nasa.gov
www.nasa.gov

LAR-15977-1, LAR-15767-1, LAR-15831-1, LAR-15831-2, LAR-15831-3, LAR-15745-1

National Aeronautics and
Space Administration

LaRC-SI

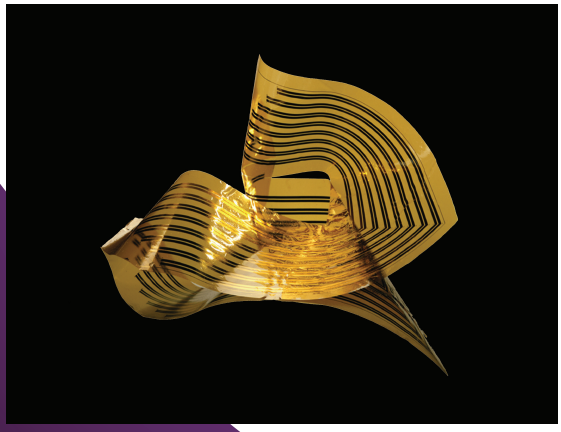
Highly flexible and durable high-temperature resins for dielectric films, coatings, composites, adhesives, and solid parts

TECHNOLOGY OPPORTUNITY

Langley Research Center (LaRC) discovered this soluble imide (SI) during an advanced aeronautics materials research program and found that this high temperature material has surprisingly good processing properties along with good machinability, solution casting, compression molding, and extrusion characteristics. LaRC-SI was quickly commercialized and has found its way into many applications, such as flexible and multilayer circuit substrates, dielectric film, wire insulation, mechanical parts, hot melt adhesive film, composites and fiber optic cladding. Because LaRC-SI is processed so easily by so many standard methods, the variety of applications that have not yet been explored far exceed those that have.

BENEFITS

- Highly flexible and durable – can be used in tight spaces
- Ease and variety of processing methods compared to other advanced polyimide materials
- Biologically inert – able to be used for medical devices, including implantables
- Recyclable unlike other advanced imides and many other intractable plastics
- Exceedingly large variety of uses because of flexibility in methods of manufacturing, resistance to chemicals, performance from cryogenic to high temperature, flammability resistance and dielectric properties, and biological inertness



COMMERCIAL APPLICATIONS

The technology offers wide-ranging market applications, including:

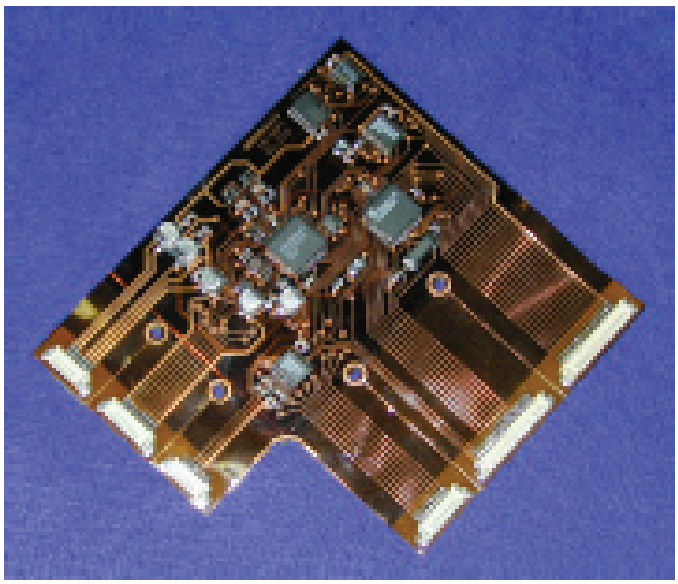
- High-temperature adhesives, coatings, and barriers (wire coatings)
- Matrix resin for composites (carbon fiber and glass)
- Electronic packaging components
- Optical cladding
- Dielectric coatings and films
- Structural or mechanical parts, either filled or unfilled
- Radiation shielding
- Flame-retardant foam (structural and flexible)
- Low pressure bonding for sandwich panel construction

TECHNOLOGY DESCRIPTION

LaRC-SI is a wholly aromatic high-performance thermoplastic polyimide that is a self-bonding/non-curing resin made from commercially available monomers. This polyimide has superior mechanical, electrical, and adhesive properties and an extensive range of processing choices that allow it to serve as either a dielectric inner layer, substrate coating, or the substrate. LaRC-SI film is made by casting or spraying a solution consisting of xylene, N-methyl-pyrrolidinone (NMP), and LaRC-SI powder. At different drying temperatures, various amounts of solvent are removed to the point where it becomes insoluble but retains its melt processability. LaRC-SI excels in the following characteristics:

- Solubility in conventional high-boiling solvents
- Melt flow and bonding properties
- Electrical properties – low dissipation factor and high dielectric strength
- Resistance to harsh environments such as radiation, cryogenic and elevated temperatures, most fluids, corrosives, and biological inertness

LaRC™-SI mechanical parts



3-Layer SI high speed A/D flex circuit board

PATENTS

Relevant base patents:
US Pat. 5,639,850US
Pat. 5,741,883US
Pat. 6,048,959

FOR MORE INFORMATION

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The Technology Gateway

National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
Hampton, VA 23681
757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
technologygateway.nasa.gov
www.nasa.gov

LAR-15205-2, LAR-15205-1, LAR-15941-1

National Aeronautics and
Space Administration

Low-Profile, Multi-Measurement Wireless Sensor

A wireless inductance-capacitance sensor used to simultaneously measure multiple measurands

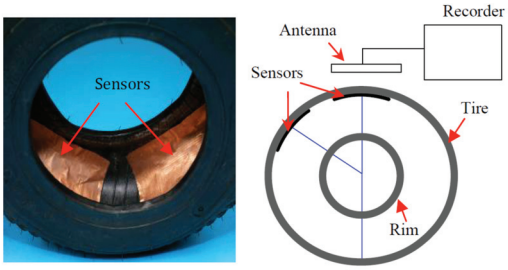
TECHNOLOGY OPPORTUNITY

NASA Langley researchers have developed a wireless low-profile sensor that uses a magnetic field response measurement acquisition system to provide power to the sensor and to acquire physical property measurements. SansEC (sans electrical connections) is a brand new system for sensing various physical quantities. It is a unique framework for designing, powering, interrogating, and manufacturing passive electrical sensors using only a single electrical component.

Unique to this sensor is the shape of the electrical traces that eliminates the need for separate inductance, capacitance, and connection circuitry. This feature gives the sensor a smaller circuit footprint to enable a smaller, flexible, and easy to fabricate sensor package. The shape of the electrical trace can be readily modified to sense different physical properties.

BENEFITS

- Receives power wirelessly, eliminating the need for a sensor power source
- Sends signals wirelessly to the data acquisition device, eliminating signal wiring
- Reduces system weight due to less wiring
- Reduces the number of electrical connections within the circuit, improving reliability
- Eliminates risk of electrical arcing in explosive conditions
- Easily modified to provide different response characteristics for sensing different physical properties simultaneously
- Inductive coupling of adjacent sensors requires only one sensor to be powered to obtain a full response from all sensors
- Enables use under corrosive, radioactive, extreme temperature, and other hazardous conditions
- Enables measurements in areas previously impractical to reach due to wiring constraints

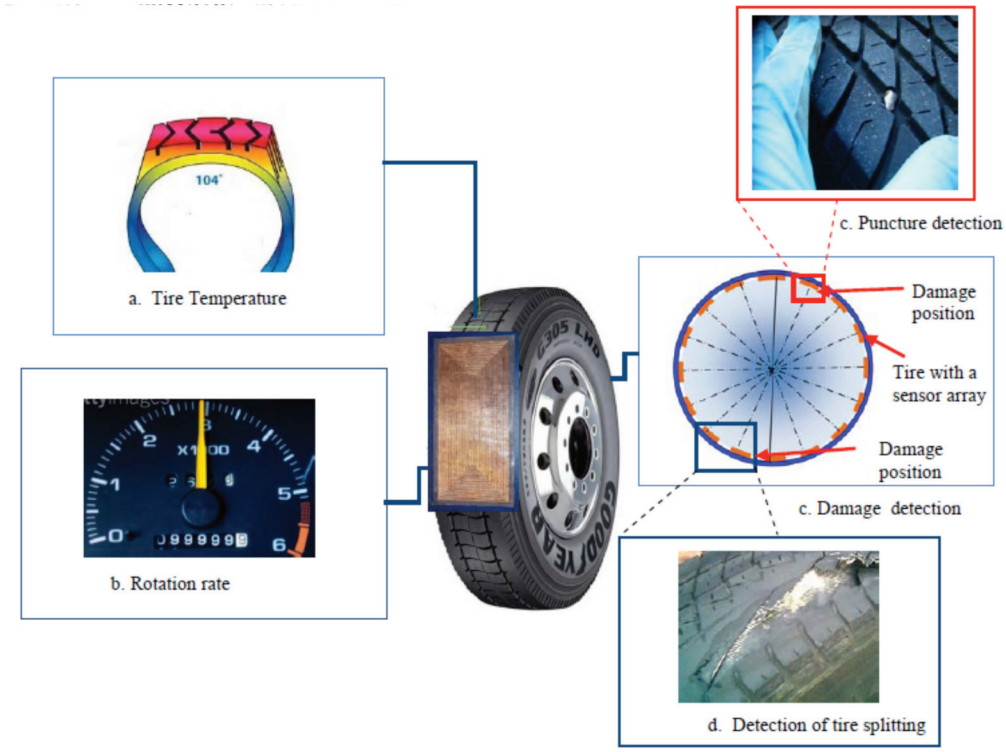


Sensor configuration and setup for sensing multiple un-related tire parameters

COMMERCIAL APPLICATIONS

The technology offers wide-ranging sensing for commercial applications, including:

- Automotive, motor sports, and trucking – tire pressure, tread wear, wheel speed, fuel level, and engine temperature
- Aerospace – landing gear health, fuselage integrity
- Industrial – foundry kiln temperature, cryogenic liquid level, materials cure process



Multiple unrelated tire parameter measured by the SansEC temperature sensor. One sensor can concurrently measure tire temperature, tire damage, and rotational rate. A sensor array can detect tire damage and damage position.

TECHNOLOGY DESCRIPTION

The low-profile sensor is configured with a spiral electrical trace on flexible substrate. In typical inductor designs, the space between traces is designed to minimize parasitic conductance to reduce the impact of the capacitance to neighboring electronics. In this low-profile sensor, however, greater capacitance is desired to allow the operation of an inductor-capacitor circuit. This allows the traces to be closer together, decreasing the overall size of the spiral trace.

The sensor receives a signal from the accompanying magnetic field data acquisition system. Once electrically active, the sensor produces its own harmonic magnetic field as the inductor stores and releases magnetic energy. The antenna of the measurement acquisition system is switched from a transmitting to a receiving mode to acquire the magnetic-field response of the sensor. The magnetic-field response attributes of frequency, amplitude, and bandwidth of the inductor correspond to the physical property states measured by the sensor. The received response is correlated to calibration data to determine the physical property measurement. When multiple sensors are inductively coupled, the data acquisition system needs to activate and read only one sensor to obtain measurement data from all of them. Various physical quantities can be measured such as: temperature, pressure, strain, structural damage, rotational velocity, and much more.

PATENTS

The low-profile sensor technology includes U.S. patent application 20070181683.

FOR MORE INFORMATION

If your company is interested in licensing or joint development opportunities associated with this technology, or if you would like additional information on partnering with NASA, please contact:

The Technology Gateway

National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
Hampton, VA 23681
757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
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LAR-17294-1

National Aeronautics and Space Administration

NASA Offers Advanced Polymers for Application in Industry

Advanced Polymer technologies developed by NASA Langley Research Center are available for creating high-performance parts, coatings, films, and adhesives.

TECHNOLOGY OPPORTUNITY

Langley Research Center (LaRC) has a long history of research and development of high-performance materials for NASA's aeronautics and aerospace missions. NASA has invested in the development of various polymer chemistries and processing improvements. All of these materials have excellent toughness and solvent resistance. NASA has numerous families of advanced polymers patents available for license. Consider the benefits these technologies offer your applications.

Table 1: Technology Comparison

Applications		IA	SI	PETI	BP	RP
ADHESIVE	hot melt	+++	+	+++	+++	+
	self-adhesive	+	+++			+
	solution coating	+	+++	+	+	+++
COATINGS	abrasion-resistant	+++	+++	+++	+++	+++
	conductive	+	+	+	+	+
	electrostatic			+++	+++	+++
	moisture-resistant	+++	+++	+++	+++	+++
	optical	+	+			+
	powder processing	+	+	+++	+++	+++
	radiation shielding	+++	+++	+++	+++	+++
COMPOSITES	complex parts			+++	+++	+++
	simple parts	+++	+++	+++	+++	+++
	matrix resin	+		+++	+++	+++
	processing—VARTM			+++	+	+
FILMS	adhesive	+++	+++			
	large area	+++	+++			
	other	+++	+++	+		

[i] When filled with conductor

+++ Best Choice + Applicable

ADVANCED POLYMER FAMILIES

Some of Langley's advanced polymer families available for licensing are described below. Table 1 presents the applications appropriate to each family and the level of benefit the NASA technology offers.

LaRC-IA—"Improved adhesive" offers processes and chemistries to lower the cost of high-performance polyimide adhesives, coatings, and films. NASA's intellectual property (IP) for this family is tailorable across various chemistries and applications.

LaRC-SI—"Soluble imide" is a unique copolymer that is soluble in the imide form and thus enables solvent coating and layered buildup.

LaRC-PETI—Includes both processes and chemistries to improve the processability of polyimide parts made of high-temperature matrix resins that can be used for very long-life applications.

LaRC-BP—"Branched polymers" enable improved processability and higher-temperature applications; these chemistries afford excellent melt flow at 15 psi for ultra-high-temperature applications.

LaRC-RP—Polyimide thermoset family exhibiting operating temperatures from -150°F to 625°F with ability to withstand spikes to 1500°F.

Table 2 offers greater insights into properties and applications.

Table 2: Specific Properties					
	LaRC-IA	LaRC-SI	LaRC-PETI	LaRC-BP	LaRC-RP
Glass Transition Temperature	230-250°C	250°C	250-280°C	200-325°C	230-393°C
Physical Chemistry	thermoplastic with no crosslinking results in extreme flexibility, and reprocessability		thermosets that by varying molecular weight between reactive end groups results in tailorable cross-link density—amount of crosslinking controls use temperature		thermoset that can be cross-linked to varied degrees with several backbone structures
Modulus	High		Tailorable		High
Processing	melt/compression moldable	can be solution cast and sprayed as either a polyamic acid or polyimide because remains soluble in imidized form; can be layered; melt processable via injection, extrusion, and compression molding	low-pressure processing (15psi), long-term melt stability (hours at 300°C), start with low molecular weight monomers but finished part has infinite molecular weight, can be powder form for VARTM processing (post melt) with no volatiles		liquid form for prepreg of carbon, glass, or quartz fabric; powder for compression molding
Various Properties	3000 psi adhesive strength hot melt or solution coating	excellent adhesion to copper, aluminum, titanium, and ceramics; solution and melt forms	able to make complex shapes, Ti-Ti, composite bonding	reactive adhesive system, able to make very complex shapes	low moisture absorption, good thermal oxidative stability and resistance to microcracking
Coatings	from solution	abrasion-resistant/ protective—on Nomex cloth for conveyor belts in drying ovens, EMI and radiation shielding, optical coatings, conductive coatings	can be sprayed, painted, or dipped with melt processing		from solution, can be painted or dipped—melt processing of partially reacted foam is possible
Aeronautics/ Aerospace	matrix resin, adhesive, or molding with self-adhesive potential with resistance heating	specialty applications	high-temperature parts, including engines, supersonic fuselage, structural heat shields, etc.		
Auto/Trucks/ Farming Equipment		moisture-resistant materials	"under the hood" in high-temperature environments		
Electronics		multi-layer printed circuit boards with increased shear strength and durability at elevated temperatures	complete parts, including connectors and other moldings		high-temp circuit boards
Products Using NASA Technology	specialty high-temperature foam—e.g., shipboard insulation	piezoelectric actuators, insulation on implantable medical electrical leads	aircraft, including military applications		randomes, engine vanes, exhaust ducts, high-temp bearings
Representative US Patents	5,478,916 5,502,127	5,741,883 6,048,959	5,664,022 6,133,401 6,288,209	5,965,687 6,191,252	6,777,525 5,171,822

FOR MORE INFORMATION

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The Technology Gateway

National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
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757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
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National Aeronautics and
Space Administration

Intelligent Power Systems

Leverage NASA's expertise, testing capability, and state-of-the-art facilities in intelligent power

TECHNOLOGY OPPORTUNITY

With over 50 years of experience in designing, developing, and testing advanced power systems, NASA's Glenn Research Center (GRC) has engineered revolutionary intelligent power management technologies that have benefitted the Nation's space program and enhanced the competitiveness of U.S. industries. Whether in the area of power generation, power management and distribution, or energy storage, NASA knows how to optimize intelligent power through a combination of hardware and software solutions. GRC invites companies to explore partnerships that can help improve power system performance and enhance the design and development of next-generation electric and hybrid electric vehicles.

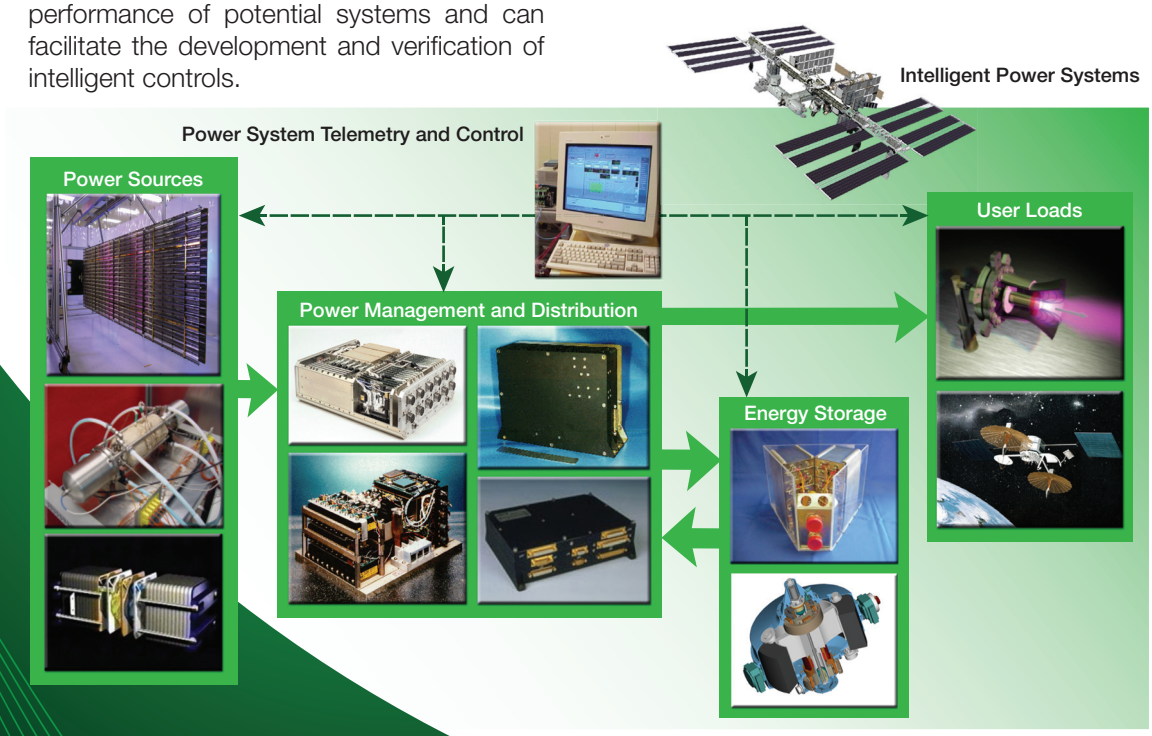
BENEFITS

- GRC expertise in intelligent power systems can be leveraged to control and manage hybrid power sources that have significant energy storage needs.
- GRC power system test facilities can accommodate integrated power system testing of novel platforms, including batteries, fuel cells, and flywheels as well as standard engines.
- GRC modeling and simulation of power systems can rapidly assess the long-term performance of potential systems and can facilitate the development and verification of intelligent controls.

APPLICATIONS

NASA's expertise, testing capability, and state-of-the-art facilities can help companies develop holistic, integrated, and intelligent power management systems. Some applications include

- Electric vehicles (EVs)
- Smart grids
- Plug-in hybrid electric vehicles (PHEVs)
- Hybrid energy storage systems
- Start/stop applications in vehicles

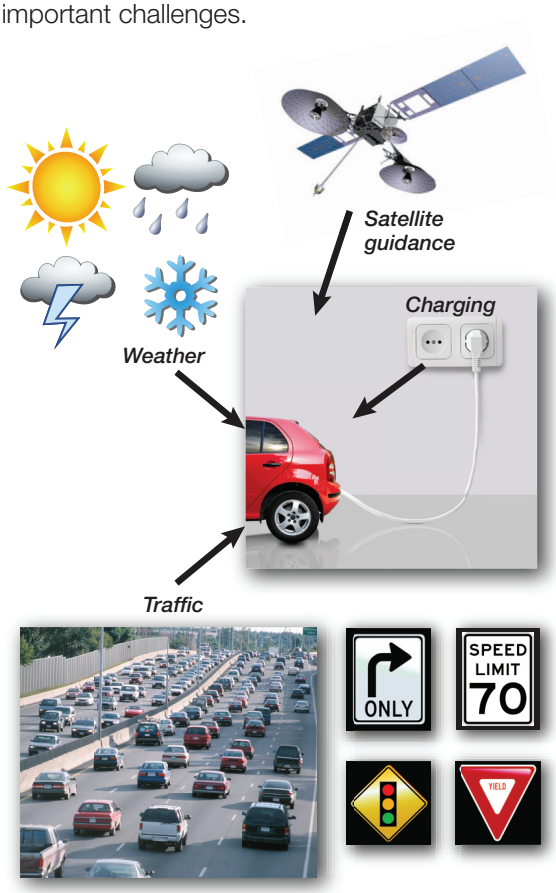


Electric Cars
AUTOMOTIVE INDUSTRY WORKSHOP

TECHNOLOGY DETAILS

To maximize the performance and efficiency of electric vehicles, the vehicle's intelligent power management systems must be integrated with other related automotive systems. Power demands must be continuously monitored and optimized with respect to (1) road and weather conditions, (2) route planning, topography/geography, and charging station locations, and (3) instantaneous traffic updates and route detours. All of this requires an intelligent power management system capable of calculating diverse bits of information in order to optimize vehicle power usage and range. Similarly, battery charging and health monitoring systems require intelligent power systems to control current, battery temperature, voltage, charging, rates to compute remaining charge, etc.

On a broader scale, intelligent power management systems must be interfaced with a smart grid infrastructure capable of managing grid capacity during charging. As the population of electric vehicles continues to grow, so does demand on the existing electric infrastructure, and this could lead to localized transformer overloads, peak demand clusters, and area brownouts. Vehicle charging in suburban environments will be a major infrastructure challenge. NASA's expertise and testing facilities can help companies solve these important challenges.



Intelligent energy management of personal electric vehicles with environment and charging infrastructure awareness.

GRC EXPERTISE IN INTELLIGENT POWER SYSTEMS

Power Controls
- Direct controller development for a wide spectrum of power generators and energy storage mechanisms
- Load management and failure diagnostics for power networks and batteries

Modeling and Simulation
- Power performance models for design assessments, and dynamic models for controller algorithm development and verification

Power Electronics
- Design and development of power converters and switchgear for multikilowatt systems

Systems Integration
- Integration and verification of power systems with multiple sources and storage

Software Development
- Design and development of software to CMMI Level 2

Advanced Sensors
- Development of high-temperature sensors for pressure and temperature

GRC EXPERIMENTAL FACILITIES IN INTELLIGENT POWER MANAGEMENT

Electric Power System Test Facility
- Provides a variety of loads and sources capable of 500 KW of power
- Accommodates sources such as fuel cells and alternators in addition to fuel cells and batteries

Power Electronics Lab
- Capability to buildup and test 10-KW-plus power electronic processing units

Fuel Cell Test Facility
- Capability to test 25-KW-plus fuel cells

Sensor Fabrication Facility
- Fabrication capability for high-temperature pressure and temperature sensors

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

High-Power Density Solid Oxide Fuel Cells

A lightweight, compact, zero emissions energy source

TECHNOLOGY OPPORTUNITY

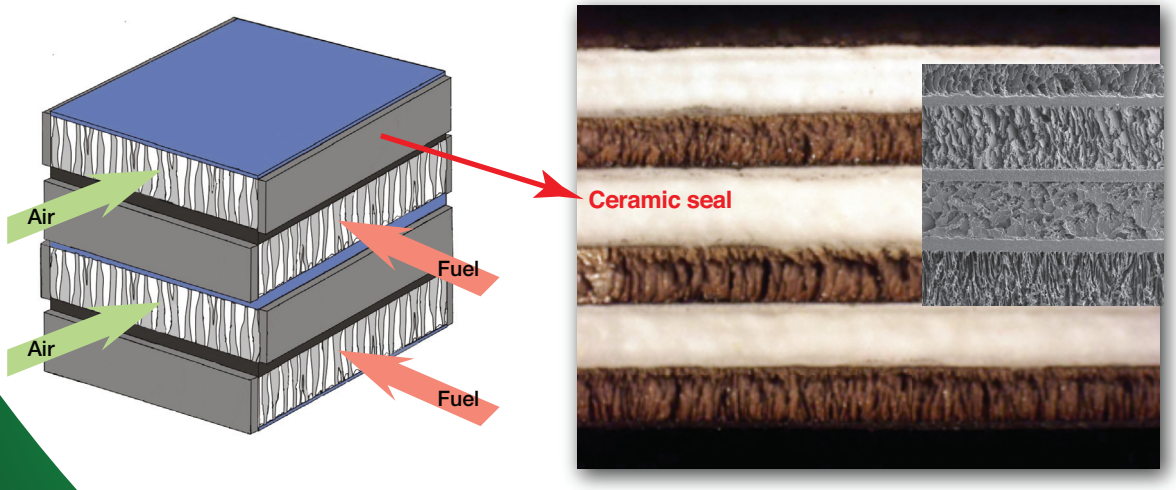
Innovators at NASA's Glenn Research Center have developed a low-cost solid oxide fuel cell (SOFC) that provides five times the power density of currently available SOFCs. Because this novel SOFC replaces the commonly used metal interconnects, such as steel and platinum, with lightweight ceramic interconnects, they are 70 percent lower in weight and volume than conventional SOFCs. NASA is looking for partners to commercialize this technology and further develop the next generation of SOFCs for both automotive and aerospace applications.

BENEFITS

- **Compact:** Lightweight and low volume
- **Fast:** Rapid startup and peak load management for battery SOFC hybrid systems
- **Efficient:** Direct conversion of fuel to electricity
- **Flexible:** Not restricted to pure hydrogen fuel
- **Robust:** Tolerant of impurities and poisons (as compared to proton-exchange-membrane (PEM) fuel cells)

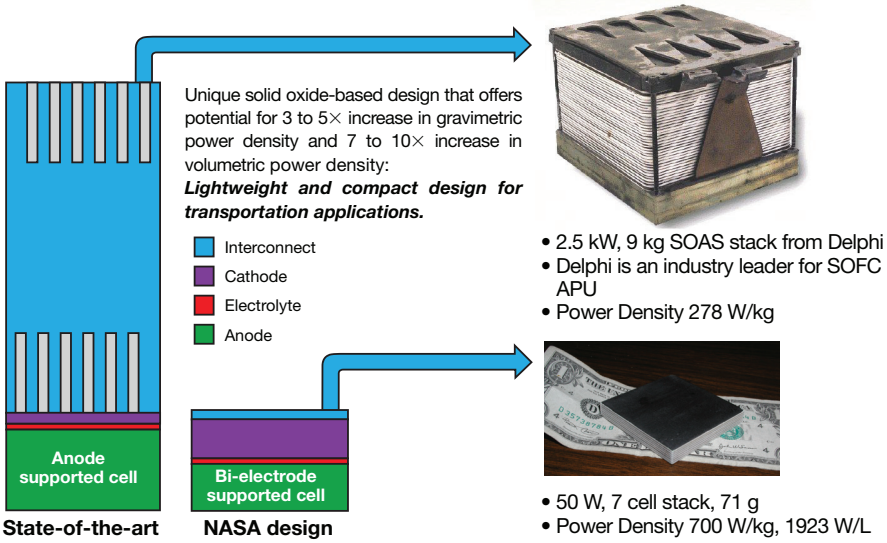
APPLICATIONS

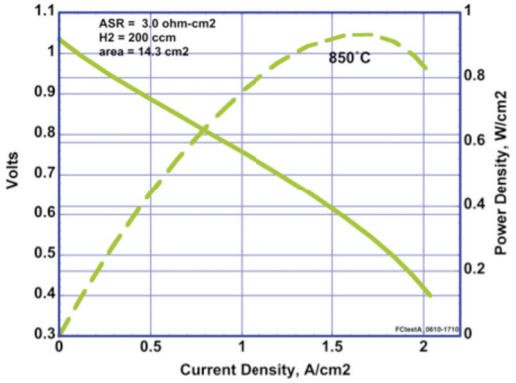
- Electric vehicles (EVs)
- Hybrid electric vehicles (HEVs)
- Plug-in hybrid electric vehicles (PHEVs)
- Auxiliary power units to support "hotel loads" for long-haul trucks and recreation vehicles



HOW IT WORKS

The cell is structurally symmetrical, with both electrodes supporting the thin electrolyte and containing microchannels for gas diffusion, creating a bi-electrode supported cell (BSC). The electrodes are made by freeze-casting, a modified tape casting technique, which creates the many microchannels in the yttria-stabilized zirconia (YSZ) electrode green tape. Since the cells are fabricated entirely from ceramic materials, they can operate at higher temperatures, and the formation of hermetic, ceramic-to-ceramic seals is possible. The high-temperature fusing of structural elements leads to strong bonding of interfaces and hermetic sealing. NASA's novel cell design replaces heavy, expensive metal interconnects with a thin, flat layer of Ca-doped $LaCrO_3$ (LCC) approximately 30 to 60 microns thick. Removal of the metal interconnects, which alone account for up to 70 percent of the weight and volume in many planar designs, provides a dramatic improvement in both the specific power density and volume density. The resulting BSC is both low volume and low weight. The BSC and interconnect repeat unit weighs only 36 g and has a volume of 10 cm^3, as compared to a standard anode-supported cell and repeat unit, which weighs approximately 199 g and has a volume of 85 cm^3. The BSC design has the potential to improve the power density by a factor of five, increasing the specific power from 0.2 to 1.1 kW/kg.





Single cell data demonstrates the power density characteristics needed to achieve >1000 W/kg.

WHY IT IS BETTER

The SOFC provides a fivefold increase in power density over comparable SOFCs, and it is anticipated that NASA's next-generation SOFC will double that figure (providing a tenfold increase in power density). The use of ceramic interconnects, rather than metal, not only lowers weight and volume but it also removes two significant challenges encountered with metal-based SOFCs: metal corrosion and metal/ceramic sealing. The uniquely lightweight and low volume design is well suited for automotive applications, as it enhances vehicle fuel efficiency and produces zero emissions. The open structure of NASA's electrodes permits operation at high fuel utilization and enables very high electrolysis efficiencies in applications where regenerative fuel cells are of interest. NASA's fuel cells can operate on a wide range of fuels, including hydrocarbon, diesel, gasoline, natural gas, propane, and hydrogen.

PATENTS

Glenn has patented this technology (U.S. Patent No. 7,534,519 B2).

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the High-Power Density Solid Oxide Fuel Cells (LEW–17630–1).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Flywheel Electromechanical Batteries

For lightweight and efficient energy storage

TECHNOLOGY OPPORTUNITY

Innovators at NASA's Glenn Research Center have developed a lightweight and efficient flywheel energy system for advanced energy storage. Flywheel energy systems are simple in concept. An electric motor is used to spin up a wheel or rotor to store energy, and energy is discharged by an electric generator, thus spinning down the flywheel. While the electromagnetic battery concept is decades old, recent advances in high strength lightweight composite materials, magnetic bearings, and power electronics technology have brought renewed interest in flywheel energy storage technologies. Advances make possible flywheel speeds that can equal or exceed the energy storage capability of traditional chemical batteries. Originally developed by NASA for energy storage on spacecraft, this flywheel technology has commercial applications in several industries, including automotive, utilities, and manufacturing.

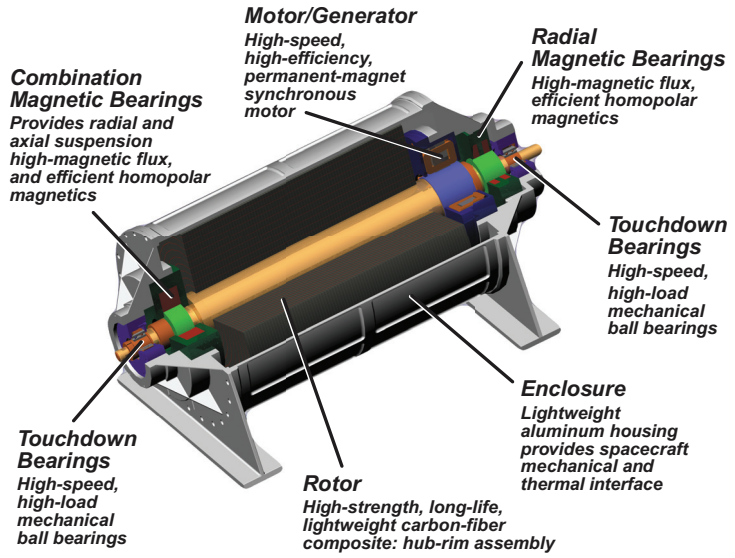
BENEFITS

- **Lightweight:** Increases applicability and reduces floor loading through lower weight per unit energy storage
- **Reliable:** Provides life expectancy that is 5 to 10 times greater than chemical batteries and reduces the mean time between failures by up to a factor of 25
- **Safe:** Uses no hazardous chemicals
- **Flexible:** Adapts to different sized systems

APPLICATIONS

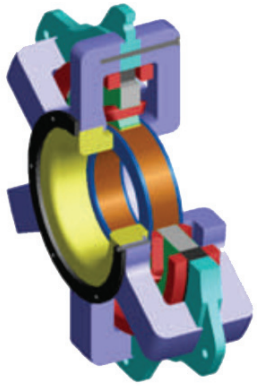
As the automotive industry increasingly relies on electric technologies for steering, suspension, braking/regenerative energy, and air conditioning, the constraints on other subsystems will become more prevalent. Flywheel technology, in conjunction with a continuously variable transmission, allows for the maximum recovery of braking energy through the elimination of energy conversions, improving overall efficiency.

- Electric or hybrid vehicles
- Pulsed power devices
- Uninterruptable power supplies
- Load-leveling applications
- Peak power applications
- Long life-cycle applications

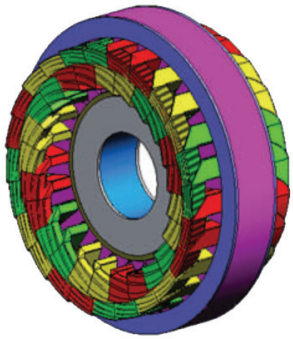


HOW IT WORKS

Flywheels store kinetic energy, as opposed to chemical energy. As energy is generated, the flywheel increases in speed by spinning up through the motor. When energy is required, the flywheel inertia is converted to electrical energy in the motor generator. Flywheel components include magnetic bearings to levitate the rotor, a motor generator for increasing the speed of the rotor and for converting rotational energy into electrical energy, a flywheel hub and composite rim that stores the energy, touchdown bearings for backup during magnetic bearing failure, and power electronics for power conversion and control. Internal converters supply power to the magnetic bearing actuators to levitate the rotor. Flywheels can be considered for use in applications that demand many charge or discharge cycles, high efficiency repeated deep discharge capability, high specific energy and power characteristics, and rapid charging or discharging capabilities.



Glenn G2 comb bearing model.

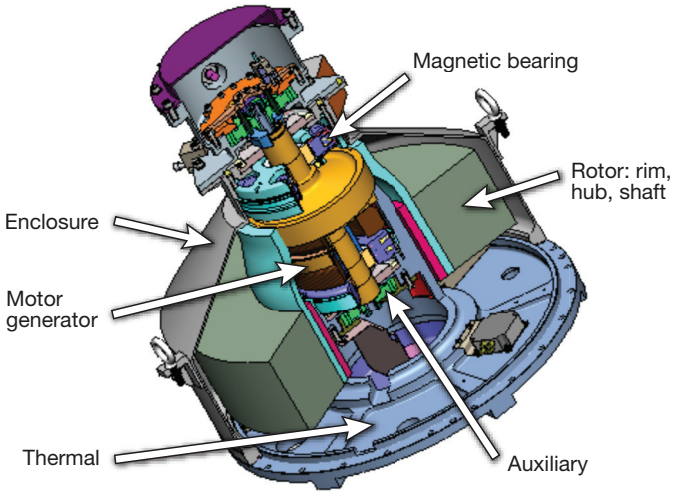


Glenn G3 motor/generator model.

Flywheel energy storage system composite rotor.

WHY IT IS BETTER

Glenn's flywheel energy system technology has the capability to provide lower weight, 5 to 10 times longer battery life, and 10 to 20 percent higher efficiencies than traditional batteries. Additionally, users can expect more reliability and greater operational flexibility. NASA is currently working the fourth generation design of a flywheel system for space and terrestrial applications. The Glenn flywheel design incorporates low loss magnetic bearings for long life and maximum efficiency, high strength composite rotor for low mass/long life/deep depth of discharge, and an advanced, proprietary motor/generator with controlled negative stiffness for high power applications. This technology allows for the further expansion of power without impacts on other subsystems.



Flywheel systems: component interaction, space environments, and controls.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to discuss partnership opportunities involving this innovative flywheel technology (LEW–17262–1) for commercial applications.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Advanced Copolymer Gel Electrolyte for Use in Electric and Hybrid Electric Vehicles

Dramatically improves battery safety and increases battery life

TECHNOLOGY OPPORTUNITY

NASA's Glenn Research Center invites companies to license its advanced copolymer gel electrolyte capable of producing batteries with higher energy density than ever before. Because it does not require the addition of volatile or flammable solvents, this new technology offers enhanced safety benefits. Cured at room temperature, the gel can hold over four times its weight in liquid additives, while maintaining good dimensional stability. NASA's gel electrolyte is environmentally friendly, inexpensive, and safe to manufacture, producing batteries with high ionic conductivity, high cycling stability, robust mechanical strength, and increased cycle life.

BENEFITS

- **Improved safety:** Requires no volatile organic compounds, producing a safer and more environmentally friendly battery
- **Improved battery life:** Provides 400 percent liquid saturation (more than four times its weight in liquid additives)
- **Lighter weight:** Uses a thin foil casing, which is 20 percent lighter than the hard shell case needed for lithium-ion batteries
- **Higher specific energy:** Enables a thinner battery
- **Flexible processing:** Accommodates both ionic and organic liquids
- **Simplified fabrication:** Straightforward synthesis method is versatile and can be cured at low temperatures
- **Increased operating temperature range:** Provides high ionic conductivity at ambient and high temperatures; can be used at subambient temperatures by employing solvents
- **Dimensionally stable:** Offers robust mechanical strength due to cross-linked rod-coil structure and aluminum oxide nanoparticles
- **Low interfacial resistance:** Aluminum oxide nanoparticles give an order of magnitude improvement at electrode interfaces

APPLICATIONS

This electrolyte technology would enhance the performance of rechargeable lithium ion polymer gel batteries in the following automotive applications:

- Electric vehicles (EVs)
- Hybrid electric vehicles (HEVs)
- Plug-in hybrid electric vehicles (PHEVs)
- Microhybrid energy storage systems
- Start/stop applications in vehicles

TECHNOLOGY DETAILS

NASA developed the technology to enhance the safety and performance of lithium-based polymer batteries used in aerospace applications, which need to work at temperatures ranging from –70 to +70 °C. NASA scientists created the electrolyte as a polyimide-polyethylene oxide (PEO) rod-coil copolymer gel with a highly cross-linked three-dimensional structure. The resulting nanoscale voids are filled with liquid and, when incorporated with ionic liquids, they can realize an increase in ionic conductivity of two orders of magnitude.

HOW IT WORKS

This technology consists of a composite material with the cross-linked structure of the copolymer, which creates nanoscale voids. The void space is filled with a liquid, and when ionic liquids are incorporated, an increase in ionic conductivity of two orders of magnitude can be achieved. Diamine and dianhydride are reacted and cured in solution to produce an amine end-capped oligomer. The reaction with a trifunctional molecule yields a fully three-dimensional, cross-linked polymer web. The rod-coil copolymer is believed to exhibit a higher liquid uptake than any other material known in a lithium-ion battery.

WHY IT IS BETTER

PEO (and materials based on PEO) is a traditional polymer electrolyte in lithium-ion batteries. However, with conventional PEO, lithium ion conductivity is two orders of magnitude too low for advanced battery designs. Also, PEO melts at temperatures above 80 ºC and does not have good dimensional stability. Other gel electrolytes for lithium batteries are made from polyvinylidene fluoride, which has a less flexible matrix, is less environmentally friendly, and is typically more expensive to manufacture.

An advanced battery made with NASA's gel electrolyte will have enhanced performance and be safer than any existing batteries, because there are no volatile or flammable components. The copolymer has a large capacity, holding more than four times its weight in liquid. Its high ionic conductivity improves lithium ion conductivity over a wide temperature range (particularly at room temperature) and enhances battery usefulness. Its cross-linked rod-coil structure and aluminum oxide nanoparticles provide mechanical strength with low interfacial resistance, enabling an order of magnitude improvement at electrode interfaces.

PATENTS

Glenn has both patents and a patent pending on these technologies (U.S. Patent Nos. 7,704,622, 6,881,820, and 6,855,433).

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Advanced Copolymer Gel Electrolyte suite of technologies (LEW–18205–1, LEW–17592–1, LEW–17299–1, and LEW–17299–2).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

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NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Electrolyzer-Based Hydrogen (H_2) Fueling Station

Enabling Technology Development and Demonstration Program
High-Efficiency Space Power Systems Project

TECHNOLOGY OPPORTUNITY

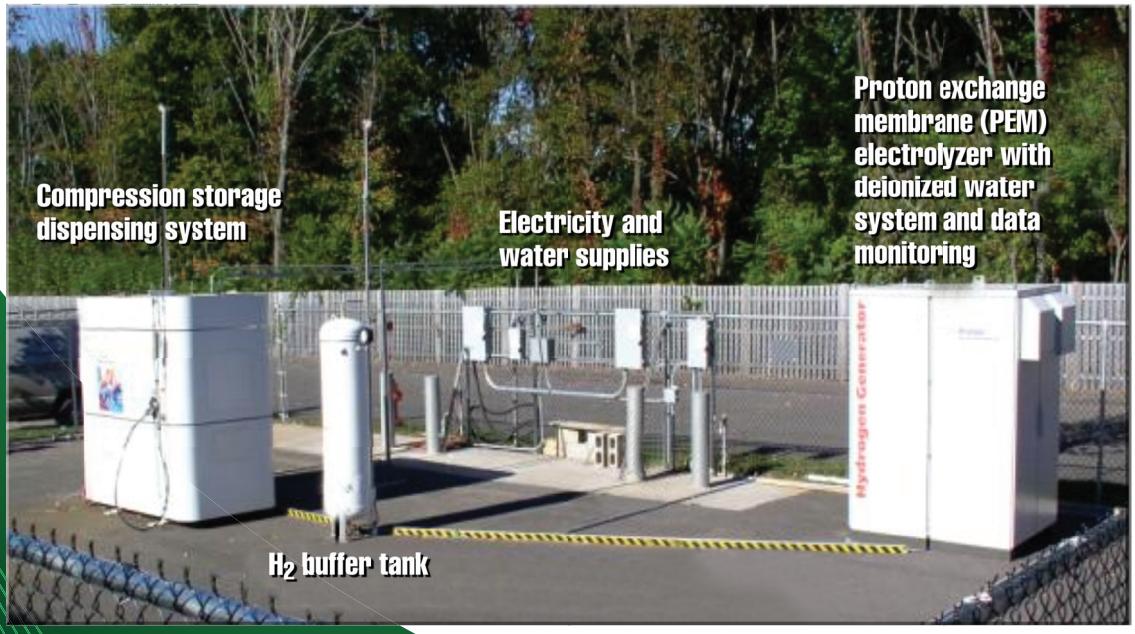
NASA's Glenn Research Center urges companies and universities to consider electrolysis-based systems to generate hydrogen gas for fuel cell vehicles. Electrolysis is a safe and efficient means of generating hydrogen gas directly from water, without emitting harmful pollutants into the atmosphere. Once the hydrogen is generated, it can be used in fuel cell buses, passenger vehicles, or stationary power systems. Replacing diesel and gasoline-powered vehicles on our roads with fuel cell vehicles would mean reducing the use of fossil fuels and reducing harmful emissions. This hydrogen fueling station will demonstrate the ability to safely, efficiently, and cleanly produce hydrogen gas to be used in actual fuel cell vehicles.

BENEFITS

- First hydrogen fueling station in the Midwest to generate its own hydrogen—electrolyzer produces H_2 directly from city water
- H_2-powered fuel cells eliminate emissions—the only exhaust is water and waste heat
- The system is scalable; it can be upgraded to produce additional H_2 as demand increases
- The station is amenable to being powered by renewable energy sources (e.g., solar, wind, and hydro) producing a zero-emissions fuel, from generation through to the tailpipe

APPLICATIONS

- The station will initially produce 12 kg H_2 per day— enough to run a fuel-cell-powered bus in revenue service
- Fuel-cell-powered passenger vehicles
- Utility and military vehicles
- Stationary power systems



HOW IT WORKS

Proton exchange membrane fuel cells, more widely known as PEM fuel cells, are a means of power generation useful for both space and terrestrial applications. The PEM fuel cell converts the chemical energy of hydrogen and oxygen into electrical energy with heat and water as byproducts of the electrochemical reaction. Direct current electricity is produced by drawing electrons through an external circuit from the anode (negative) to the cathode (positive). The hydrogen and oxygen gases are stored in external storage tanks, allowing the fuel cell to generate power as long as fuel is available. For terrestrial applications, air is substituted for stored oxygen, eliminating the need to generate/purchase and store oxygen gas. In a fuel cell bus, the diesel engine is replaced with a fuel cell to generate the power necessary to run the bus. Advantages of replacing the engine with a fuel cell include the elimination of harmful emissions (only heat and water are emitted), reduction of moving parts, and virtually silent operation.

In contrast, the reverse reaction of splitting water into hydrogen and oxygen is called electrolysis. The hydrogen fueling station employs an electrolyzer system to generate the hydrogen necessary to fuel the PEM fuel cell in the bus. The electrolyzer intakes city water, purifies it via an internal deionizing process, and uses electricity to split the water into hydrogen and oxygen gases. The generated hydrogen is then stored in tanks to be pumped to the hydrogen storage tank on the bus for use in the fuel cell. Electrolysis is a safe, efficient, and clean method of generating hydrogen gas since there are no harmful emissions. The uses for the generated hydrogen gas are not limited to only fuel cell buses, but passenger vehicles, utility vehicles, and stationary power systems that employ fuel cells as well.

WHY IT IS BETTER

The application of electrolysis to generate hydrogen gas from water eliminates pollutant emissions. The only emissions from the fuel cell bus are heat and water. The electrolysis system is amenable to renewable energy sources as its source of electricity, which would make it a truly "green" system, further helping to eliminate harmful pollutants and reduce the country's dependence on fossil fuels. Research at Glenn is focused on improving the reliability and efficiency of PEM fuel cell and electrolysis systems.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA urges companies and universities to consider electrolysis-based systems to generate hydrogen gas for fuel cell vehicles.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
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Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Global Elevation Data Adaptive Compression Algorithms

Providing greater compression and faster decompression of digital terrain maps

TECHNOLOGY OPPORTUNITY

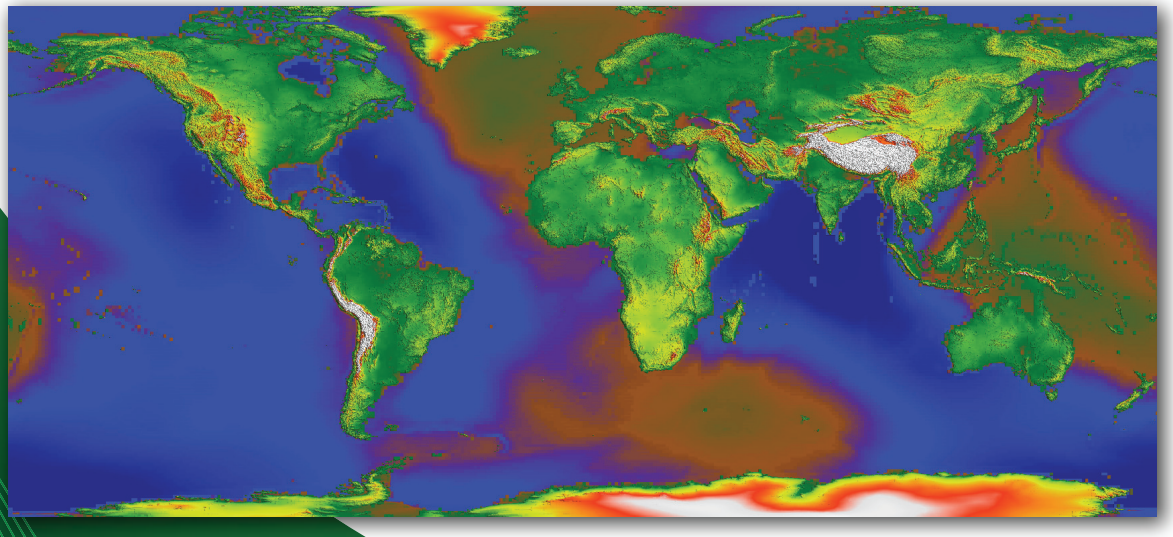
NASA's Dryden Flight Research Center invites companies to consider licensing the Global Elevation Data Adaptive Compression Algorithms (GEDACA) for further development and commercial applications. This patent-pending innovation provides compression and rapid decompression of digital terrain maps (DTMs) in constrained computing environments. With the ability to integrate more than 250 billion separate pieces of terrain information in a single compressed DTM, uses include applications that require large databases of graphical information deployed via restricted environments such as tablets and smart phones.

BENEFITS

- **Effective:** Controls error induction maximums for user-defined geographical areas from lossless to infinite and incorporates different areas seamlessly in a single compressed DTM
- **Fast:** Performs rapid, high-performance decompression in real-time constrained computing environments
- **Powerful:** Integrates more than 250 billion separate pieces of terrain information into a single compressed DTM
- **Proven:** Features technology flown and tested on several different platforms including high-performance fighter aircraft
- **Economical:** Offers industry standard C, C++ code base and map formats

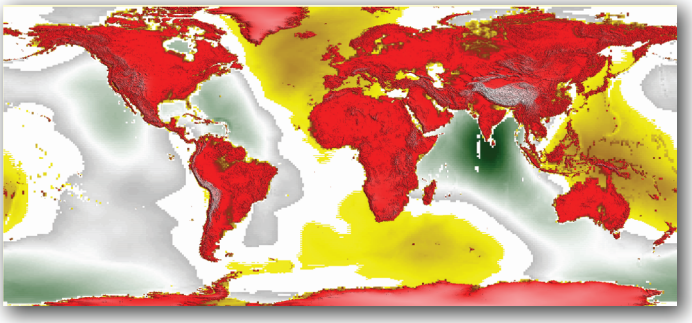
APPLICATIONS

- Global Positioning Systems (GPS)
- Any software that rapidly computes line of sight
- Any software that analyzes and plans terrain routes or analyzes continual surfaces



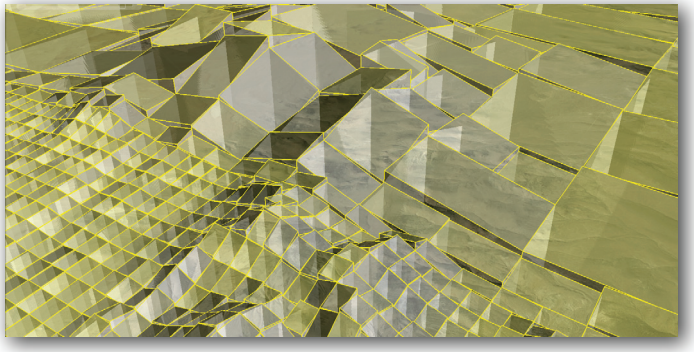
TECHNOLOGY DETAILS

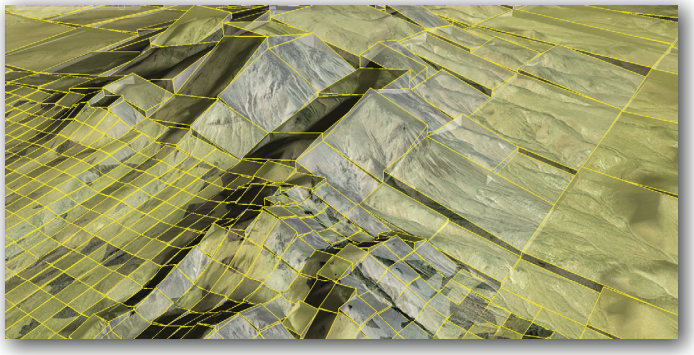
The GEDACA software provides an extensive and highly efficient compression capability for continental and global-scale DTMs, along with a real-time decompression capability to locally decompress and render map data.



HOW IT WORKS

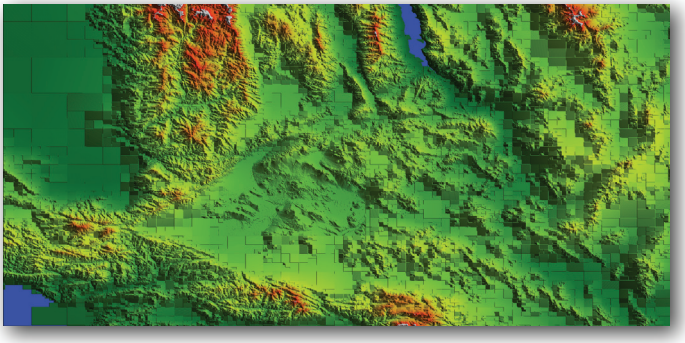
The GEDACA software achieves its high-performance compression and decompression capability using a unique combination of regular and semiregular geometric tiling allowing for the use of particular benefits of each aspect and the ability to mitigate the drawbacks of others. Geometric facets are fit to the data through linear regression or adaptive regression techniques and arranged in a combination structure. This allows for important slope information to be retained and continuous terrain representation to be generated, enabling the possibility of high-resolution decompression.





WHY IT IS BETTER

Generally, the more accurate a DTM is, the larger the resulting file size, presenting a problem for constrained computing environments. Because the GEDACA software provides high compression ratios with real-time decompression using a recursive semiregular tree-based compression that utilizes linear regression geometric tiling, resulting file sizes fit within the memory limits of conventional systems. Additionally, the ability to selectively tailor information for specific geographical areas enables high-fidelity sections of terrain data to be incorporated seamlessly into maps. This allows for compression trades to be localized and satisfy size requirements for a larger number of applications.



PATENTS

Dryden has applied for patent protection for this technology.

LICENSING AND PARTNERING OPPORTUNITIES

This technology is part of NASA's Innovative Partnerships Office that seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Global Elevation Data Adaptive Compression Algorithms (DRC–009–008) for further development and commercial applications.

FOR MORE INFORMATION

Julie Holland
PO Box 273, MS 1100
NASA's Dryden Flight Research Center
Edwards, CA 93523–0273
Phone: 661–276–2515
E-mail: julie.a.holland@nasa.gov

National Aeronautics and
Space Administration

Automotive Stirling Technology

Supplying electrical and mechanical power with high-fuel efficiency and low emissions

TECHNOLOGY OPPORTUNITY

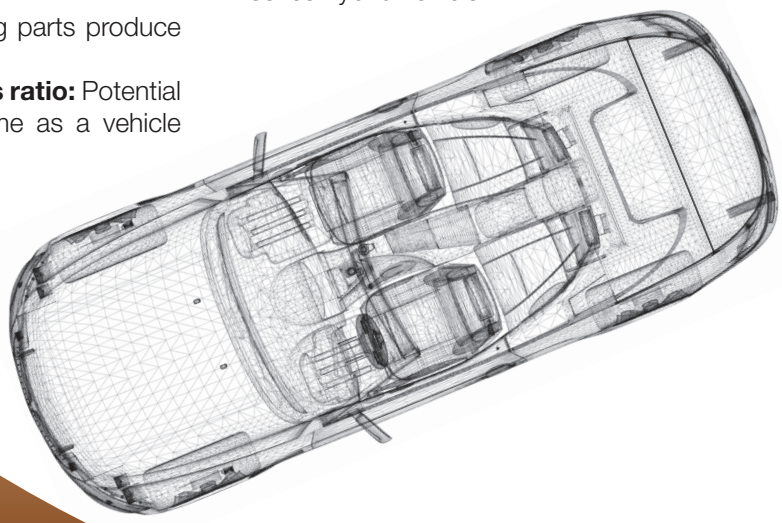
NASA's Glenn Research Center invites companies to establish partnerships to develop its automotive Stirling engine. This external combustion heat engine can provide either electrical or mechanical power output. Developed under the space power program, the free-piston design features high fuel efficiency and ultralow emissions and offers reliability and improved performance over internal combustion engines (ICEs).

BENEFITS

- **Ultraefficient:** Offers up to 40 percent thermal-to-electric conversion efficiency, compared to 18 to 20 percent for ICEs
- **Multifuel capability:** Can use any heat source (solar, air, hot water, and even liquid sodium) depending on the application
- **Clean, green technology:** Ultralow CO_2 emissions as the technology uses steady combustion rather than quick bursts
- **Free-piston design:** Enables operation at design resonant frequency where piston motion is converted to electricity via linear alternator; displacement can be adjusted to modulate power output
- **Friction-free properties:** No contact and no wear mechanisms increase system reliability and product life
- **Long-life operation:** Design eliminates loss mechanisms such as seals and lubrication pumps
- **Quiet:** Noncontacting moving parts produce fewer vibrations
- **Unmatched power-to-mass ratio:** Potential for low mass and low volume as a vehicle auxiliary power unit (APU)

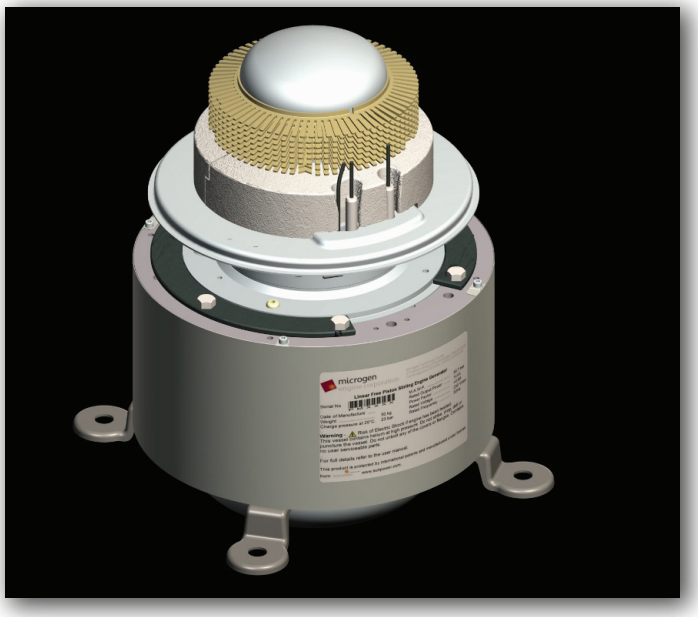
APPLICATIONS

- Primary power source alternative to the ICE
- APU that could operate via ICE's waste heat
- Fuel-fired generator supplying electricity for battery charging and electric drive motor in series hybrid vehicle



TECHNOLOGY DETAILS

Stirling technology is a critical component of the Advanced Stirling Radioisotope Generator (ASRG), a high-efficiency candidate power source for future NASA space science missions. Glenn's unique facilities have allowed for more than 400,000 hr of reliability testing and operation on experimental models and flight prototypes.

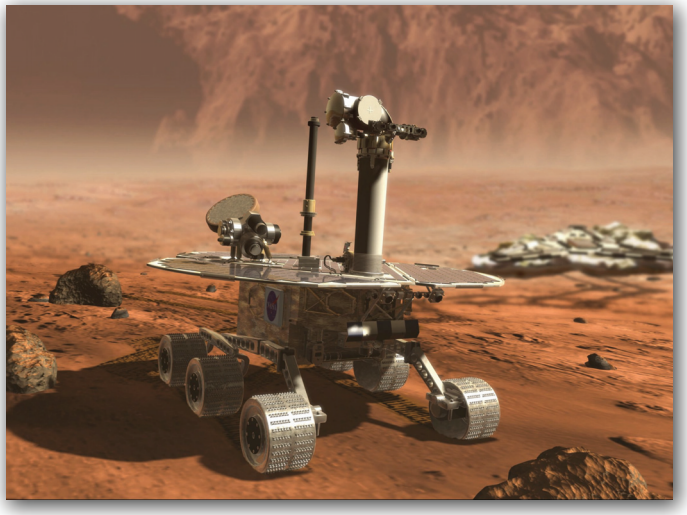


HOW IT WORKS

A displacer shuttles gas between hot and cold zones to raise and lower gas pressure. The resulting pressure wave moves the piston, which has no contact with the cylinder wall. The piston motion is converted to electricity via a linear alternator. There are no linkages or crankshafts in the free-piston design, as the motion of the displacer is excited by the pressure wave that it creates. All moving parts are suspended by gas bearings or planar springs.

WHY IT IS BETTER

Motion of the displacer and piston is tuned via the spring/mass/damping resonant dynamics, eliminating the need for complex mechanisms. The noncontacting operation between the moving components eliminates inherent friction and the resulting wear on mechanisms and ensures long-life operation. The Stirling engine's high conversion efficiency, capability for long-life operation, and high specific power make it a candidate for automotive power systems.



LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider partnering with Glenn to further develop this automotive Stirling technology.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Affordable Joining and Repair Technologies for Ceramics and Composites

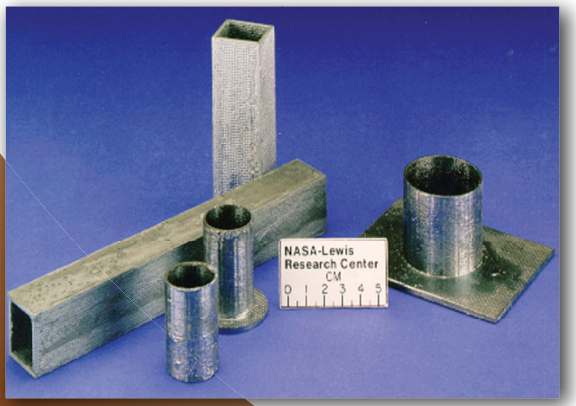
For low-cost manufacturing and repair of lightweight, high-temperature components

TECHNOLOGY OPPORTUNITY

Scientists at NASA's Glenn Research Center, in collaboration with the Ohio Aerospace Institute, have developed innovative processes, which help prolong component life, reduce replacement costs, and enable wider use of ceramics and composites. These technologies also improve the structural, thermal, and mechanical properties and performance of ceramics and ceramic matrix composites (CMCs). Ceramic joining technologies (LEW–16405–1, LEW–16661–1, and LEW–17009–1) enable low-cost manufacturing of ceramic components into large, robust, and three-dimensional shapes, including curved surfaces and internal cavities. Robust composite repair technologies (LEW–18390–1) refurbish and restore worn or damaged CMC components to prolong component life and reduce replacement costs. These award-winning technologies offer significant benefits for numerous systems (e.g., thermoelectric, batteries, supercapacitors, etc.) by providing lightweight components, longer component life, and lower costs for parts, operation, and maintenance.

BENEFITS

- **Enables greater use of ceramics and CMCs:** Enables the fabrication and application of ceramic and CMC components
- **Advantages over metals:** Components are lighter weight and insulative, with higher temperature capability and greater resistance to corrosion, wear, and thermal shock
- **Enables complex shapes:** Allows for large three-dimensional shapes to be fabricated, including curved surfaces and internal cavities
- **Robust:** Maintains good joint strength and integrity up to 1400 °C and higher
- **Increases component life:** Restores CMC durability and restores resistance to heat, corrosion, and wear
- **Reduces replacement costs:** Restores worn or damaged components
- **Low-cost manufacturing:** Integrates easily into various manufacturing processes; joint properties can be tailored



Ceramic composite joining.

APPLICATIONS

- Piston heads and rings; seals and cam rollers
- Cylinder sleeves
- Oxygen sensors
- Components for braking systems
- Engine valves for race cars
- Turbocharger rotors
- Gas turbine components for energy systems
- Heat exchangers and recuperators and radiant heater tubes
- Components for electronic industries and solar power systems

HOW IT WORKS

Robust joining and repair processes allow for low-cost manufacturing, longer component lives, and wider utilization of ceramics and CMCs. In ceramic joining, advanced silicon-carbide-based ceramic materials are bonded to one another to build up complex-shaped ceramic components. Typically, ceramic and CMC parts are limited to simple two-dimensional shapes due to processing limitations from methods using sintering, hot pressing, chemical vapor deposition, and fiber pre-forming. Ceramic joining allows for large three-dimensional shapes to be fabricated that may include curved surfaces or internal cavities. In composite repair, the worn or damaged CMC is refurbished to restore material properties, prolong durability, and reduce replacement costs. NASA's joining and repair technologies have received a NorTech Innovation Award and two R&D 100 awards.

Testing of repaired specimens.

Flexible repair patches and high-temperature gaskets.

WHY IT IS BETTER

Ceramic components offer several benefits, including lighter weight, higher temperature capability, better thermal insulation for lower heat losses, and increased durability through improved resistance to heat, corrosion, and wear. Such benefits translate to lower costs for parts, operation, and maintenance. As an example of benefits, CMC brake rotors have been developed that reduce vehicle weight by 10 lb, last the life of the vehicle, and triple brake pad life. The use of ceramic joining to fabricate the brake system and composite repair to refurbish the pads can lead to reduced fabrication costs and increased part life. Similarly, CMC clutches have been developed that offer an 8 lb weight reduction, smaller size, improved wear, and high-temperature resistance.

Light-weight carbon-carbon composite valves for race car engines.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Ceramic and Composite Joining and Repair suite of technologies (LEW–16405–1, LEW–16661–1, LEW–17009–1, and LEW–18390–1) and/or partnering with NASA Glenn in this area.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

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Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Ceramic Integration Technologies for Dissimilar Materials

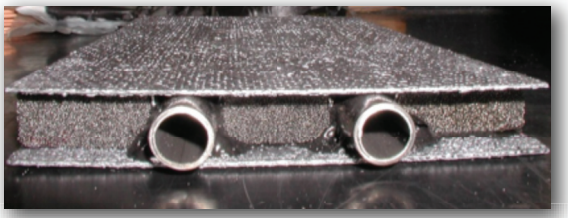
For integration and low-cost manufacturing of energy-efficient components and systems

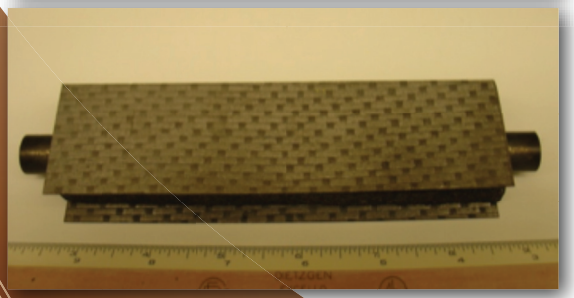
TECHNOLOGY OPPORTUNITY

Scientists at NASA's Glenn Research Center and the Ohio Aerospace Institute have developed innovative approaches to integrate ceramics to metals. This novel process allows for greater utilization of advanced ceramics and composite components in high-performance energy and environmental systems. Through ceramic integration technologies, dissimilar materials can be bonded together to create components that are more durable, lightweight, energy efficient, and wear resistant than ever before. These methods offer significant benefits for the automotive industry, including lighter weight components, longer component life, and lower costs for parts, operation, and maintenance. NASA's novel process enables robust manufacturing of components used in automotive support systems, including thermal management, energy production, energy storage and distribution, and energy conservation and efficiency.

BENEFITS

- **Enables greater use of ceramics and ceramic matrix composites (CMCs):** Dissimilar materials can be bonded together to create more durable, lightweight, and wear-resistant components
- **Advantages over metals:** Components are lighter weight, and insulative, with higher temperature capability and greater resistance to corrosion and wear
- **Improves vehicle performance:** Vehicles will be more durable, fuel efficient, and safe; reduces costs, heat losses, and weight
- **Low-cost manufacturing:** Integrates easily into various manufacturing processes; joint properties can be tailored
- **Enables complex shapes:** Allows for large three-dimensional shapes to be fabricated, including curved surfaces and internal cavities
- **Robust:** Maintains good joint strength and integrity in various operating conditions

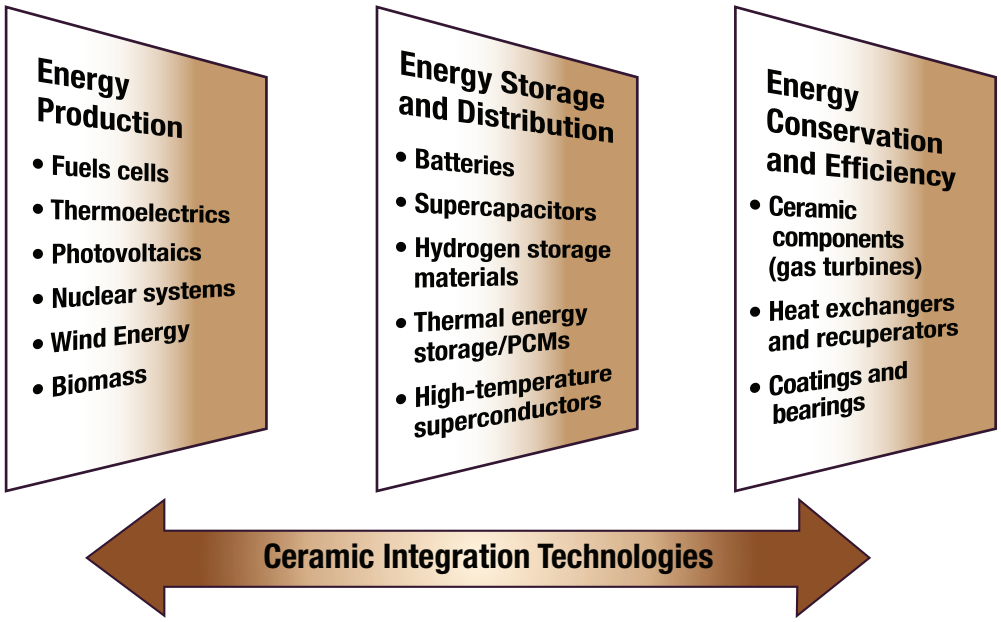




Heat exchanger components.

APPLICATIONS

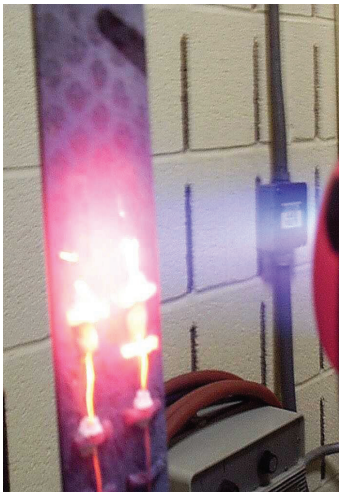
- Systems for piston heads and rings; turbo-charger rotors
- Packaging of sensors and actuators
- Energy production systems
  - Fuel cells, thermoelectrics, photovoltaics, nuclear systems, and wind energy
- Energy storage and distribution systems
  - Batteries, supercapacitors, thermal energy storage/phase change materials (PCMs), and high-temperature superconductors
- Energy conservation and efficiency systems
  - Ceramic components (gas turbines), heat exchangers and recuperators, coatings, and bearings



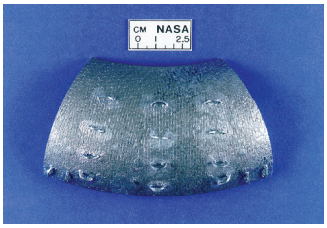
Integration technologies are critical for various energy systems.

HOW IT WORKS

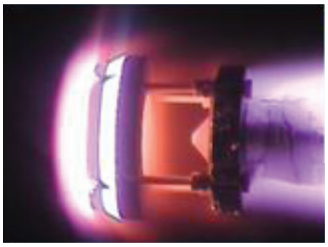
Ceramic-metal integration technologies allow robust bonding and assembly of a wide variety of components, allowing for longer component lives and wider utilization of ceramics and CMCs. In this process, ceramic or CMC materials are bonded/brazed to metals using metallic interlayers (active braze alloys or solders). A number of ceramic-metal systems (including oxides, such as alumina and yttria-stabilized zirconia (YSZ), and nonoxides, such as silicon carbide and silicon nitride) have been bonded to different metals for use in automotive energy, environmental, and thermal management systems. This process enables the integration of ceramic components into various automotive support systems, such as cooling (e.g., metallic manifolds), fuel (e.g., metallic fuel tubes), and monitoring and performance-based maintenance (e.g., sensor and actuators).



Attachment for sensors.



Attachment for integration of sensors.



Testing.

WHY IT IS BETTER

Ceramic components offer several benefits, including lighter weight, higher temperature capability, improved electrical insulation, and better thermal insulation for lower heat losses. They also enhance durability through improved heat capacity and greater resistance to corrosion and wear. Such benefits translate to lower costs for component parts, operation, and maintenance. These technologies are critical for the manufacturing of next-generation energy-efficient systems with reduced cost and improved efficiency.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider licensing the Ceramic Integration Technologies.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

GRCop-84Z

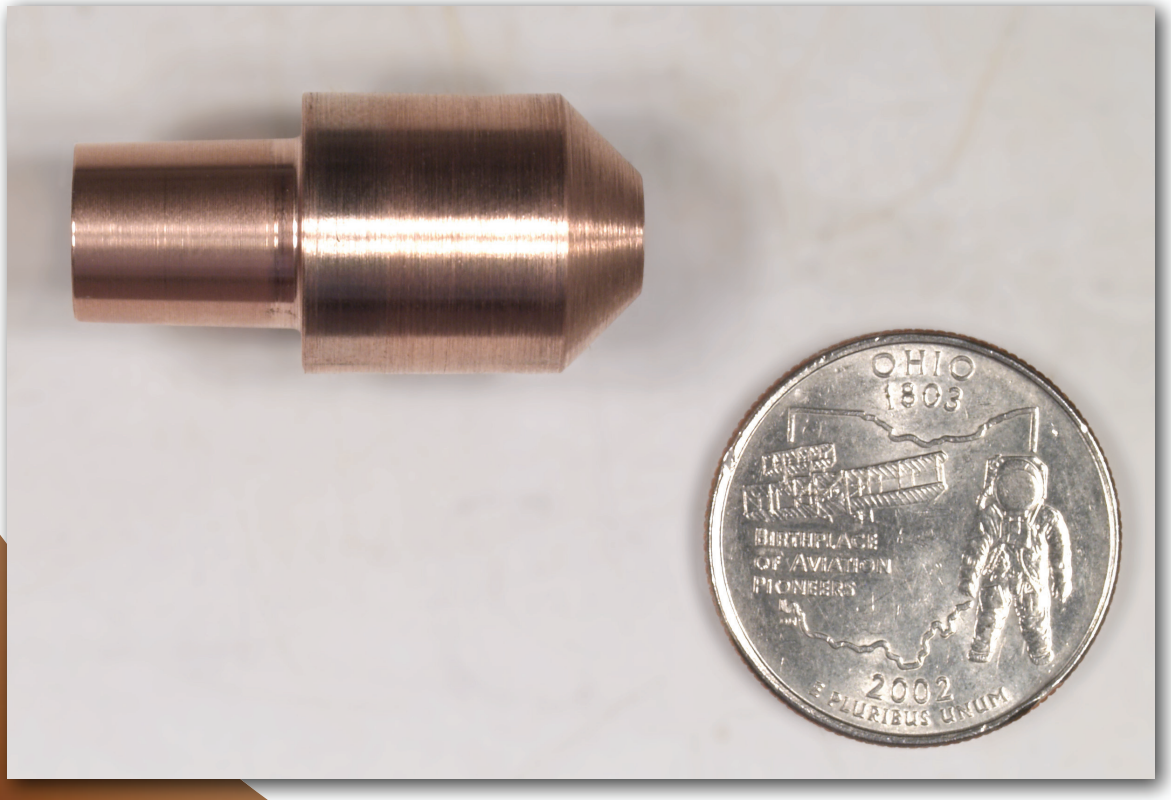
A better alloy for resistance welding electrodes

TECHNOLOGY OPPORTUNITY

NASA's Glenn Research Center invites companies to establish partnerships to investigate the use of GRCop-84Z for resistance welding electrodes. GRCop-84Z is a copper-based alloy that shows significant improvements in creep rate and low-cycle fatigue (LCF) life when compared to GlidCop AL-15.

BENEFITS

- **Flexibility:** Wide variety of powder metallurgy and other conventional processing techniques can be used
- **Higher strength:** Higher room and elevated temperature strength means that the welding electrodes will not deform as much under welding mechanical loads
- **Longer electrode life:** Lower creep rates and longer creep lives (up to 3 times compared to GlidCop AL-15), and better LCF life (up to 2 times compared to GlidCop AL-15) means longer electrode lives
- **Higher quality welds:** Because the welding electrodes will deform slower and less, the quality of the weld will remain high for a longer period of time. This will improve overall quality and longevity

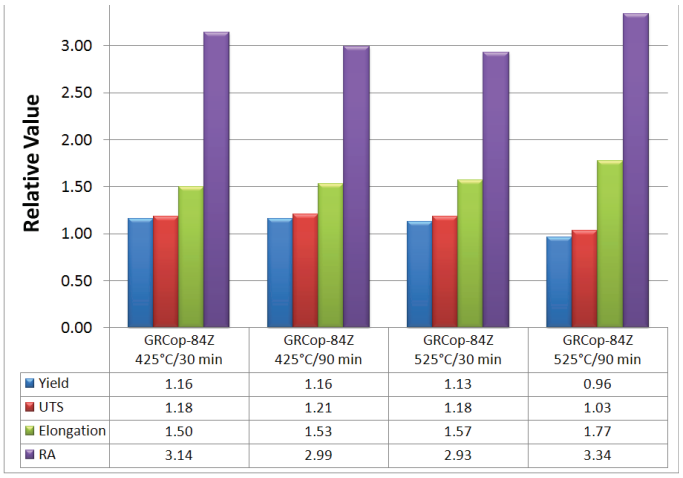


TECHNOLOGY DETAILS

GRCop-84Z is a copper-based alloy originally developed for rocket engine liners requiring high temperature strength. GRCop-84Z is a copper base alloyed with 6.7 percent chromium, 5.8 percent niobium, and 0.5 percent zirconium. The resulting alloy has exceptional high temperature strength and creep resistance as well as improved LCF life. Initial welding characterization testing of GRCop-84Z indicates that this alloy will be a game changer for resistance welding electrode applications. Significantly increased creep life and LCF properties of GRCop-84Z offer the potential to increase electrode life by a factor of 2 to 3 times.

HOW IT WORKS

GRCop-84Z has the addition of a small quantity of zirconium, which when used for electrode tips, helps to resist sticking of the tips to zinc-coated materials.

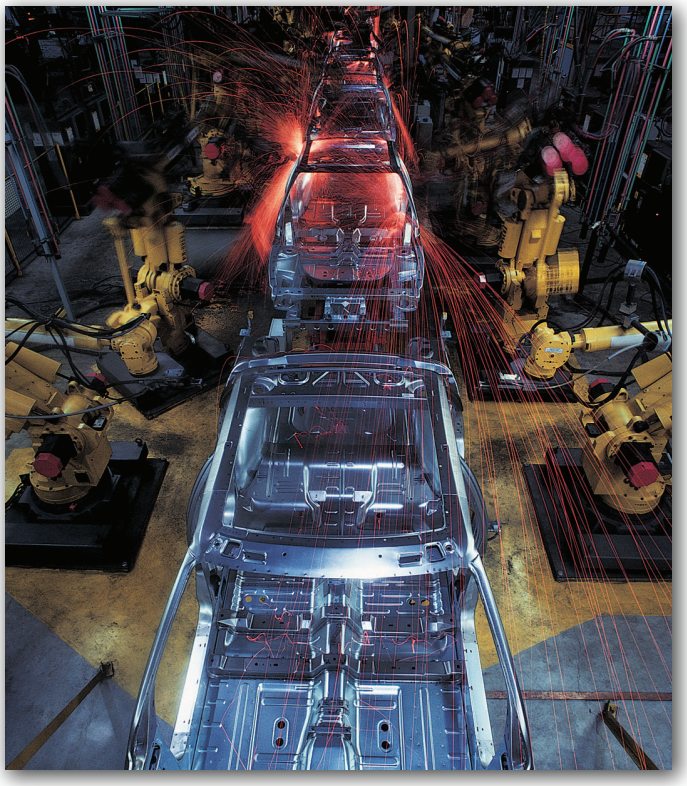


	GRCop-84Z 425°C/30 min	GRCop-84Z 425°C/90 min	GRCop-84Z 525°C/30 min	GRCop-84Z 525°C/90 min
Yield	1.16	1.16	1.13	0.96
UTS	1.18	1.21	1.18	1.03
Elongation	1.50	1.53	1.57	1.77
RA	3.14	2.99	2.93	3.34

500 °C tensile properties of GRCop-84Z relative to GlidCop AL-15.

WHY IT IS BETTER

High-quality, more consistent welds will improve overall car production quality. GRCop-84Z properties when compared to GlidCop AL-15 will result in longer electrode life and improved weld quality. The increased welding electrode life will also lead to less assembly line maintenance and less downtime.



LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to partner with NASA Glenn Research Center in the use of GRCop-84Z for use as a welding electrode alloy or for other automotive applications.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Use of Beam Deflection to Control Electron-Beam Wire Deposition

Advanced process control technique for electron-beam free-form fabrication and welding

TECHNOLOGY OPPORTUNITY

NASA Langley researchers have a strong technology foundation in the use of electron-beam (e-beam) deposition for free-form fabrication of complex shaped metal parts. While e-beam wire deposition is of interest for rapid prototyping of metal parts, cost-effective near-net shape manufacturing, and potential use in space, it is also of intense interest for industrial welding and fabrication in a range of applications, from small components to large aerospace structures. Through significant advancements in techniques to improve control of the process, NASA greatly expands upon the capabilities of the e-beam fabrication and welding process.

BENEFITS

- Self-correcting—stabilizes and optimizes e-beam heating of the wire during the deposition process
- Provides continuous and predictable deposition pattern
- Simplifies deposition of complex geometries
- Optimizes microstructural control of the solidified molten metal
- Provides efficient use of power and feedstock
- Improves automated operation

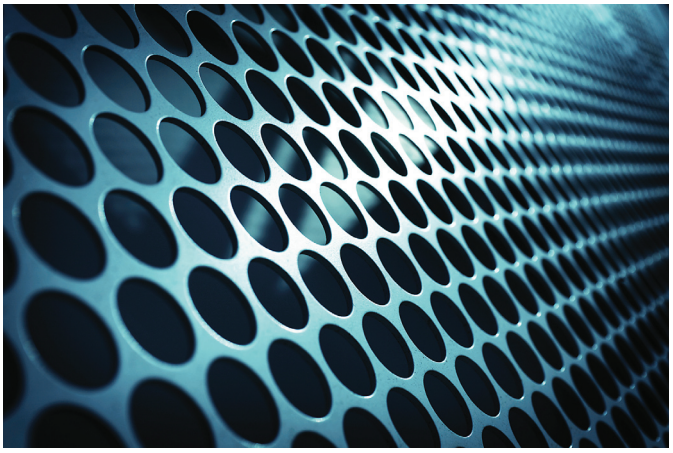
APPLICATIONS

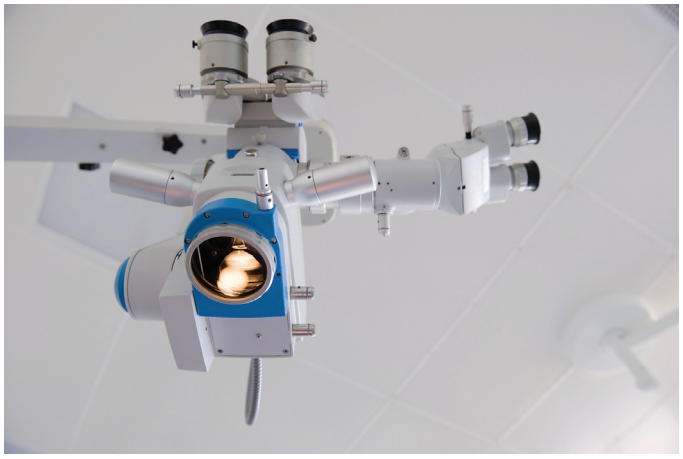
The technology offers wide-ranging market applications, including

- Welding of metal structures for automotive, aerospace, and other industrial and commercial manufacturing
- Free-form fabrication of complex metal components in remote locations
- Near-net shape manufacturing and rapid prototyping
- Applicable to variety of metal fabrication markets, from automotive and aerospace to sporting goods and medical devices

TECHNOLOGY DESCRIPTION

The technology employs rastering of the e-beam in the region of the wire and substrate melt zone. By controlling the raster pattern, the e-beam selectively heats the outer edges of the wire as it strays from the melt zone. With such selective heating, the wire automatically curls back away from the high heat outer edge and back into the region of the molten pool. Thus, with a fixed raster pattern, the process becomes self-correcting without any sensing or external control of process parameters.





PATENTS

NASA Langley Research Center has submitted a patent application for this technology.

FOR MORE INFORMATION

If your company is interested in licensing or joint development opportunities associated with this technology, or if you would like additional information on partnering with NASA, please contact:

The Technology Gateway

National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
Hampton, VA 23681
757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
technologygateway.nasa.gov
www.nasa.gov

LAR-17245-1

National Aeronautics and
Space Administration

Electron Beam Freeform Fabrication (EBF^3) Technology for Additive Manufacturing of Metal Parts

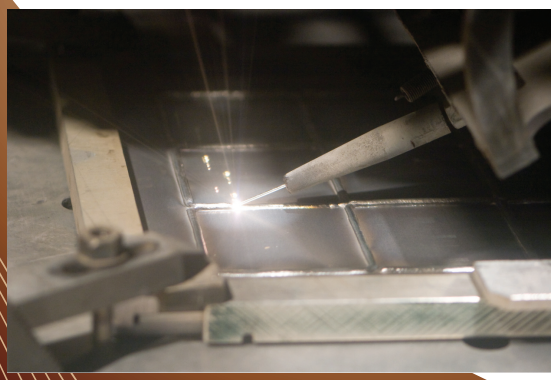
Cost-effective manufacturing of near-net-shape metallic components using less time, less energy, and less raw materials.

TECHNOLOGY OPPORTUNITY

NASA Langley Center has developed an additive manufacturing process for building near-net-shape metal parts directly from CAD geometry without molds or tooling. EBF^3 is a scalable, cost-effective replacement for traditional forging and machining to produce metallic parts and for on-demand repair or fabrication of replacement parts. EBF^3 can be considered a "green manufacturing" technology in that it produces parts equivalent to those fabricated via conventional machining processes but uses less time, less energy and less raw materials. The process is ideal for custom fabrication, low production runs and prototypes.

BENEFITS

- Scalability – EBF^3 is capable of producing parts at higher deposition rates across a much larger size range than competing laser and electron beam systems using powders.
- Transfer Efficiency and Handling – Wire feedstock for EBF^3 is far easier to handle and does not have pyrophoric or explosion hazards associated with metal powder. 100% of the wire is captured in the part, with 10–15% material removal required for finish machining to final geometry.
- Energy Efficiency – Electron beams are extremely efficient energy sources, with up to 90% of the energy used by the system output in the electron beam.
- Geometric Flexibility – The EBF^3 process can build parts with overhangs, undercuts and embedded geometric features that are very difficult to machine.
- System Utility – The EBF^3 process operates in a modified pre-existing electron beam welding system.



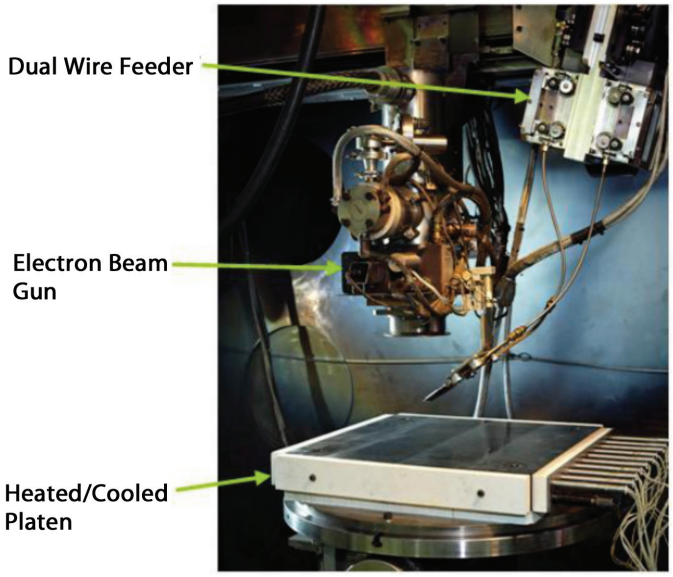
APPLICATIONS

The technology offers wide-ranging market applications, including:

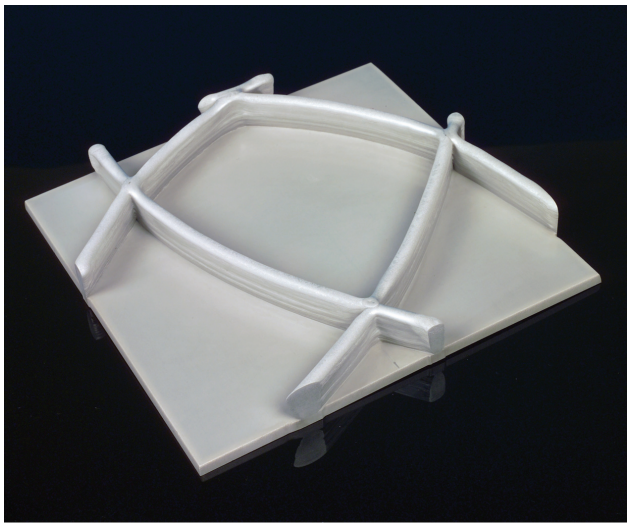
- Fabrication or repair of tooling and dies for high volume part production (such as molds for plastic or metal forming used in the automotive industry)
- Aircraft components (wing/fuselage stiffened structures, pressure vessels, bulkheads, spars, ribs, engine cases)
- Support of electrical power generation and other systems requiring high availability
- Launch vehicle structures (isogrid/orthogrid stiffened structures including pressurized, cryogenic fuel tanks)
- Custom manufacturing industries (custom-built motorcycle and automobile components, out-of-production parts for vehicles or heavy machinery)
- Prototype components (first-run concept vehicle demonstrators, functional wind tunnel test models)
- Medical implant devices (load-bearing hip or bone implants tailored for the patient)
- Fabrication or repair of oil and gas drilling bits and hardware
- On-demand repair or replacement parts for Navy submarines and ships in service, field-deployed Army combat units, remote scientific bases
- Space-based manufacturing (build in space for use in space, fabrication of large space structures otherwise impossible to launch from Earth)

TECHNOLOGY DESCRIPTION

Current computer-aided machining practices start with a solid CAD model and use a post-processor to write the machining instructions (such as G-code) defining the cutting tool paths needed to make the part. EBF^3 uses a similar process, starting with a CAD model, slicing it into layers, and then using a post-processor to write the code defining the deposition path and process parameters for the EBF^3 equipment. The EBF^3 process uses a focused electron beam in a vacuum environment to create a molten pool on a metallic substrate (Figure 1). The beam is translated with respect to the surface of the substrate while metal wire is fed into the molten pool. The deposit solidifies immediately after the electron beam has passed, having sufficient structural strength to support itself. Careful attention to the process design is still required to minimize deformation until the part cools. A part is thus built directly from a CAD file in a layer-additive fashion without molds or tooling dies. The electron beam can be precisely steered to control the size of the molten pool and facilitate capture of the wire. The wire is preheated by the beam but is not melted until it enters the molten pool.



The EBF^3 system.



FOR MORE INFORMATION

If your company is interested in licensing or joint development opportunities associated with this technology, or if you would like additional information on partnering with NASA, please contact:

The Technology Gateway

National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
Hampton, VA 23681
757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
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LAR-17245-1, LAR-17766-1, LAR-17248-1, LAR-17566-1, LAR-17695-1

National Aeronautics and
Space Administration

Crimping Tool for Safe and Efficient Critical Wiring Needs

Tool connects wires to end-connectors and nondestructively verifies crimp quality during the crimping process

TECHNOLOGY OPPORTUNITY

NASA Langley researchers have developed an enhanced crimp tool that provides real-time verification of wire-crimp integrity while the crimp is being formed. The tool nondestructively tests crimp connection quality in aircraft and other critical wiring systems. Modern commercial aircraft rely on thousands of crimped wire terminations for critical communication, navigation, control, and electrical power distribution systems. Wiring crimp failures can be a threat to aircraft safety and may lead to a loss of critical functions or an onboard fire. In addition to the safety concerns, diagnosing and repairing poor crimp connections is costly. By enabling an efficient way to directly test all crimps as they are made, the new tool improves quality control and reduces the risks of failure.

BENEFITS

- Improved quality control: Enables direct and practical testing of all crimp connections, compared to current procedures that rely on a combination of a rigorous crimp protocol and periodic spot checks to destructively evaluate representative crimps
- Improved safety: Allows direct testing of all crimp connections as they are made
- Reduced costs: Lowers risk of failed crimp connections that are costly to replace
- Real-time confirmation of crimp integrity

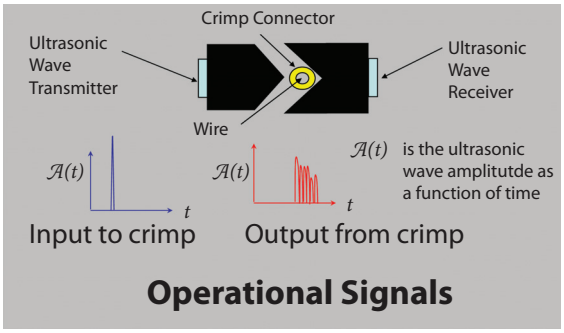
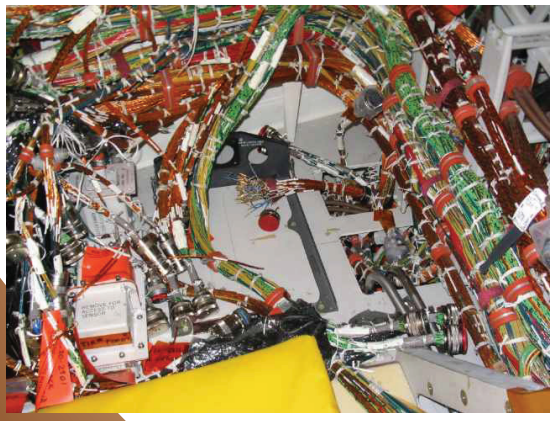


Figure 1: Basic concept of ultrasonic equipped crimp tool



APPLICATIONS

This technology can improve safety and reduce costs related to installing and/or overhauling crimp/wire connections in industries with critical wire terminations, such as:

- Marine
- Automotive
- Industrial plants
- Nuclear power plants
- Medical devices

TECHNOLOGY DESCRIPTION

The tool is based on traditional ultrasonic nondestructive evaluation methods. The quality of the contact between the connector and wire is determined by sending an acoustic wave through the crimp assembly. Figure 1 depicts the interrogation of a crimp connector. As the applied pressure increases and the crimp terminal deforms around the wire, the ultrasonic signature passing through the crimp is altered. The tool analyzes the changes in the signal, including the amplitude and frequency content, as an indication of the quality of both the electrical and mechanical connection between the wire and terminal.

Figure 2 shows the ultrasonic response of a crimped connector. Various crimp quality issues such as under-crimping, missing wire strands, incomplete wire insertion, partial insulation removal, and incorrect wire gauge have been tested using this technique, and results show that the instrumented crimp tool consistently discriminates between good and poor crimps for all of these potential quality issues. This information can be used to provide a “pass” or “fail” indication to the technician for instant verification of the crimp quality and to give a better prediction for the service life of the crimp.

The system has been prototyped and tested and is in use at NASA. Figure 3 shows the prototype instrumented crimp tool.

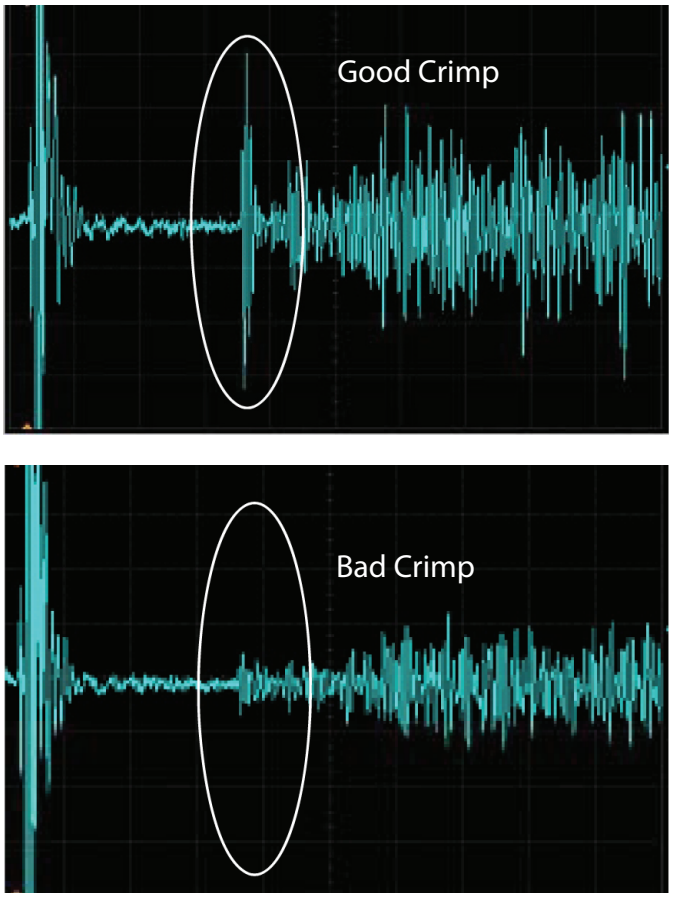


Figure 2: Ultrasonic response of a crimped connector

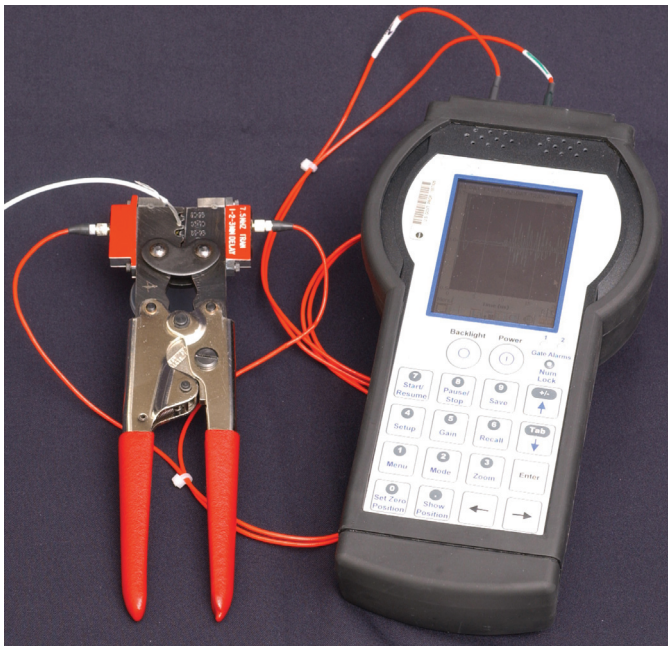


Figure 3: Prototype instrumented crimp tool

FOR MORE INFORMATION

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National Aeronautics and Space Administration
Langley Research Center
Mail Stop 218
Hampton, VA 23681
757.864.1178
LARC-DL-technologygateway@mail.nasa.gov
technologygateway.nasa.gov
www.nasa.gov

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National Aeronautics and
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Advanced Materials Design Analysis Tools

Designs that are more affordable, lower weight, and efficient

TECHNOLOGY OPPORTUNITY

NASA's Glenn Research Center has developed a suite of software tools that provides accurate, efficient, and effective modeling and design support when using advanced materials, including smart materials and composites. The tool, Integrated multiscale Micromechanics Analysis Code (ImMAC), is a comprehensive, computationally efficient, and user friendly design analysis toolset used for accurately predicting behavior of all continuous- and discontinuous-reinforced composite materials (polymer, ceramic, and metal-matrix) and smart materials (shape memory alloys and piezoelectric). Due to its extreme level of computational efficiency, ImMAC tools are ideally suited for conducting sensitivity/parametric studies, that is, "what-if" scenarios, with a large number of cases.

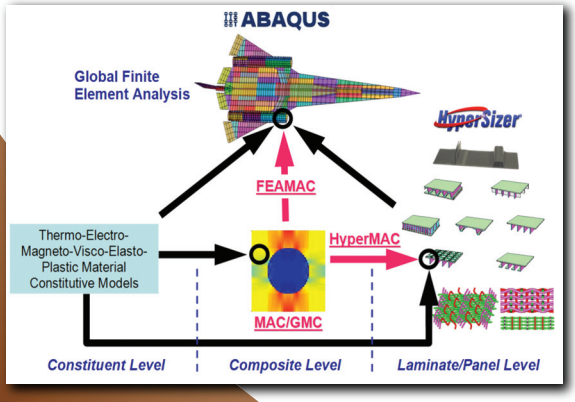
ImMAC is composed of three primary components:

- **Micromechanics Analysis Code (MAC)/Generalized Method of Cells (GMC):** Performs rapid, standalone analysis of composite/smart materials and laminates based on efficient non-Finite Element Analysis (FEA) micromechanics methods
- **FEAMAC:** Couples the efficient micromechanics capabilities of MAC/GMC with the ABAQUS finite element code for nonlinear multiscale analysis of composite structures including damage, failure, and viscoplasticity
- **HyperMAC:** Couples the MAC/GMC micromechanics capabilities with the HyperSizer stiffened structural optimization software

BENEFITS

Through the use of ImMAC and its ability to couple to powerful design and analysis tools, you can achieve

- **Improved material and component reliability** through better design and analysis
- **Conduct design trade studies** optimizing performance versus cost more efficiently
- **Decreased engineering costs** due to decreased need for redesign—get it right faster
- **Quicker adoption of the right materials** with costs savings associated with reducing testing
- **Access to the toolset while maintaining proprietary data** since the analysis tool is secure and will not share your data



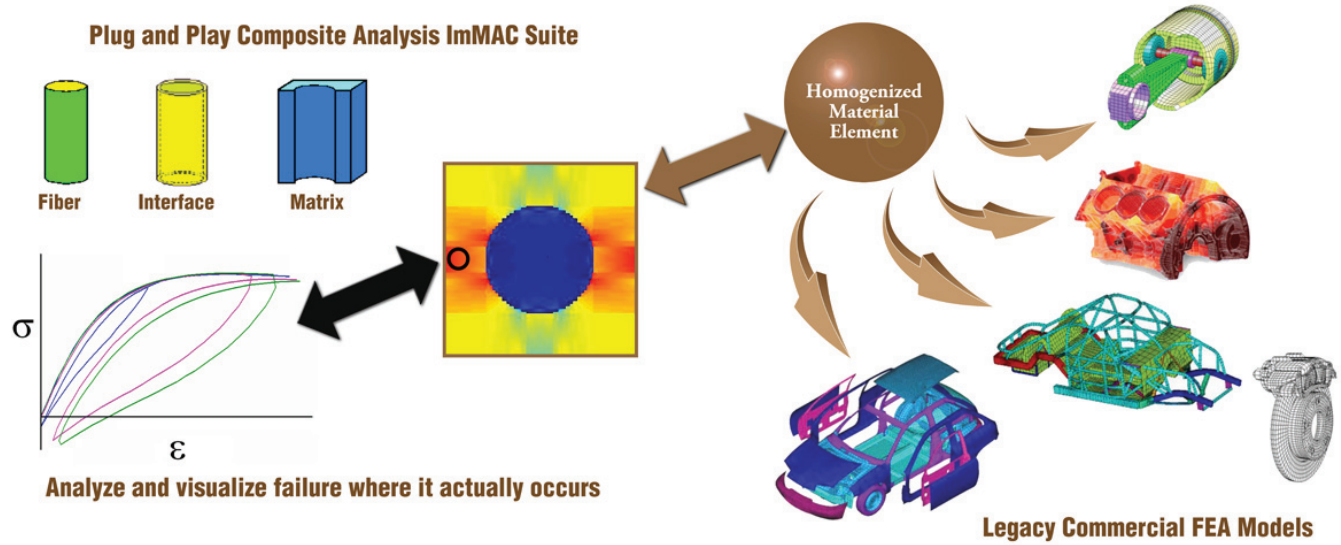
APPLICATIONS

ImMAC can be applied in numerous automotive applications that require design and analysis of components using advanced materials and composites. This includes

- Body
- Suspension/chassis
- Closures/fenders
- Multifunctional panels and frames wherein stress, thermal, acoustic, and vibration load management is achieved within a monocoque material system

HOW IT WORKS

The ImMAC toolset is fully maintained and distributed to over 90 customers in industry, government, and academia, with extensive user manuals and published test cases. The power of ImMAC has been validated through aerospace research use for over 15 years. ImMAC was successfully used to optimize the belt angle and develop a new tire (resulting in two patents) design with 28 to 50 percent improvement in durability at various speeds. Results were also obtained in a fraction of the time it normally took; for example, a two-ply composite analysis task that took more than 3 days to complete (preprocessing, analysis, and post-processing) using the traditional FEA approach (with submodeling instead of rebars so that local fields could be obtained) was accomplished in a matter of minutes (typically 45) using FEAMAC. The ImMAC infrastructure takes advantage of modern programming languages for storing and accessing data and employs dynamic memory allocation. The modular construction of ImMAC enables collaborative development of capabilities across users as selected limited source code can be exposed to outside developers while keeping the bulk of the source protected in compiled libraries. ImMAC was designed to support user-defined proprietary constitutive and damage/failure models/rules and to protect the company's proprietary data.



WHY IT IS BETTER

ImMAC allows for much more effective and efficient design of components and systems that utilize advanced materials and composites, as well as providing an excellent means of assessing damage. Material/component damage, for example, fiber failures, matrix damage, and interface debonding, can be modeled based on the local stress fields throughout the structure, and the effects of this damage progression on the global structural response can be simulated. This higher level design and analysis design toolset provides for a more proactive and effective approach to incorporating advanced materials and composites into your product lines. Through use of ImMAC, you can now capitalize on the great benefits that use of these materials can bring including

- Weight reduction due to higher structural integrity per unit mass
- Lower costs from lower part count and near net-shape manufacturing capability
- Structural versatility based on the highly tailorable properties of composites

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider utilizing the ImMAC toolset (LEW–16,487–1; LEW–17495–1; LEW–17818–1; LEW–17819–1; and LEW–18544–1).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

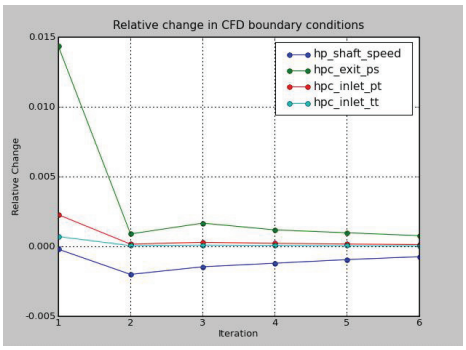
National Aeronautics and
Space Administration

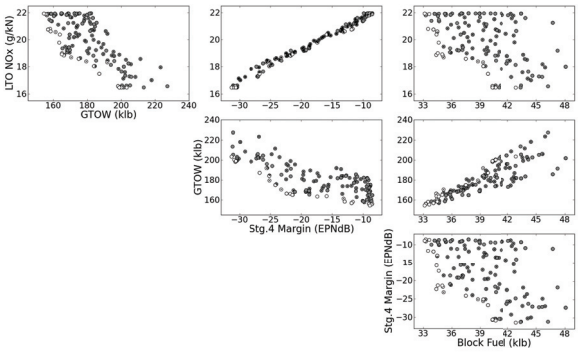
Multidisciplinary Design Analysis and Optimization (MDAO)

A software framework for system-level design optimization

TECHNOLOGY OPPORTUNITY

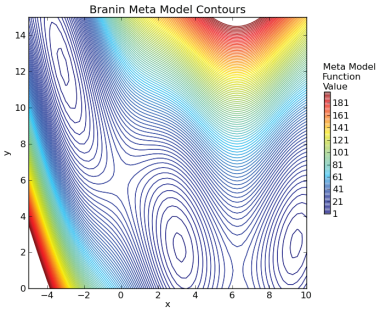
NASA's Glenn Research Center invites companies to establish partnerships to explore the use of OpenMDAO for design optimization. MDAO techniques provide a means to simultaneously consider design issues such as performance, fuel efficiency, crash worthiness, manufacturability, and cost early in the design phase of a product.

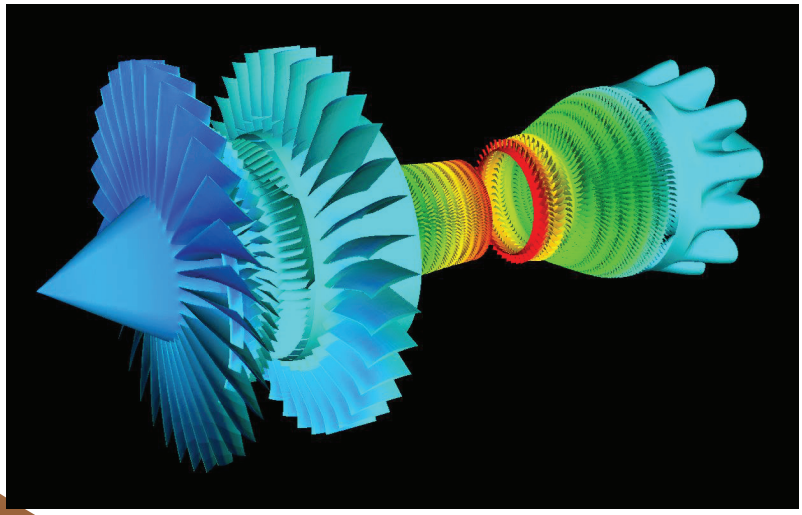




BENEFITS

- **Versatile:** Framework allows integration of separate discipline codes (e.g., C, C++, and FORTRAN) through direct memory wrappers or file wrappers
- **Maintains proprietary integrity:** Nonviral open source license (Apache V2.0)
- **System level evaluation tool:** 80 percent solution prior to preliminary design





Design Tools

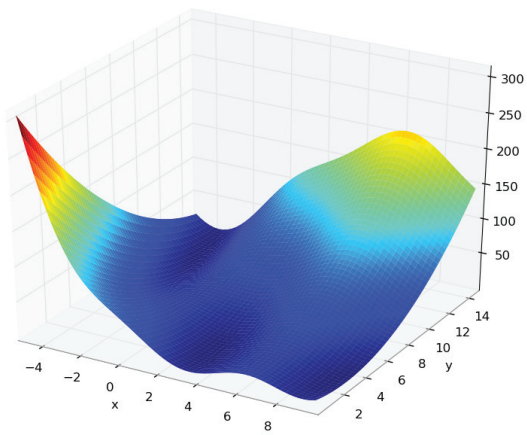
AUTOMOTIVE INDUSTRY WORKSHOP

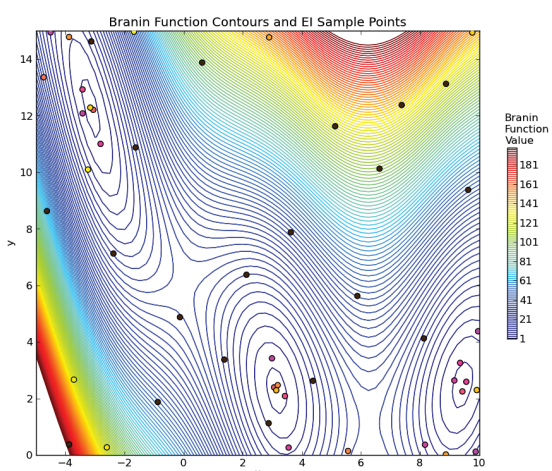
TECHNOLOGY DETAILS

Studies have shown that when optimizing for system-level metrics (cost, fuel burn, crash worthiness, interior volume, etc.), the design of individual subsystems can end up being nonintuitive. MDAO techniques provide a means to simultaneously consider multiple design issues. OpenMDAO provides a suite of tools to facilitate the integration of existing analysis codes, prototype new analysis methods, and connect all of those things together into a comprehensive system model so that MDAO can be easily applied to your problems.

HOW IT WORKS

MDAO is a Python-based engineering software framework that facilitates the linking of analysis and codes together from multiple disciplines at varying levels of fidelity. It also provides a number of solvers and optimizers (e.g., genetic, gradient-based, Broyden, and Gauss-Seidel Solver algorithms.) OpenMDAO is distributed under terms of the Apache License V2.0, a nonviral open source license.





WHY IT IS BETTER

OpenMDAO is being used by researchers at a number of universities (Purdue, Stanford, MIT, University of Michigan, and Georgia Tech) to investigate advanced MDAO tools and techniques. DARPA Vehicle Forge and META are investigating OpenMDAO as a base framework to work from.

OpenMDAO can be deployed across a large organization very easily because there are no licensing restrictions. It provides built-in capability to develop new analysis tools and integrate them with previous tools. It enables optimization, even when expensive analyses such as CFD and FEA are being used, by providing a simple interface to surrogate modeling methods.

The goal of the OpenMDAO team is to develop a common software framework that the engineering community at large can share and jointly develop. Being an open source project means that users are welcome to adopt, change, and modify the framework as they see fit. That flexibility is one of the most valuable features of OpenMDAO.

LICENSING AND PARTNERING OPPORTUNITIES

Glenn's Office of Technology Partnerships and Planning seeks to transfer technology to and from NASA to benefit the space program and U.S. industry. NASA invites companies to consider adopting OpenMDAO and contributing back the OpenMDAO project any improvements that are made (Applied for LEW in 2009).

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

Office of Technology Partnerships and Planning
NASA Glenn Research Center
Email: otpp@grc.nasa.gov
Phone: 216–433–9701

National Aeronautics and
Space Administration

Materials Data Management Software

Enables more affordable, efficient, and sustainable designs

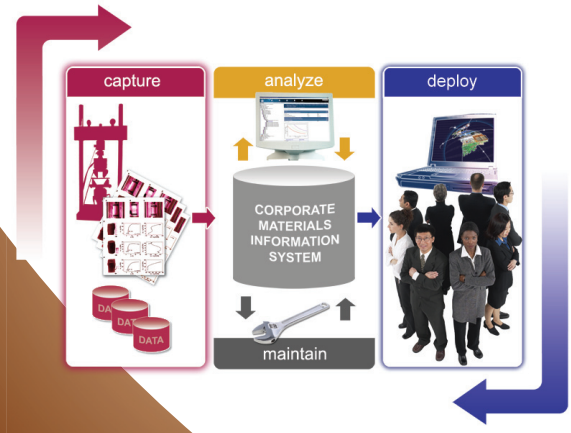
TECHNOLOGY OPPORTUNITY

The Material Data Management Consortium (MDMC), co-founded by NASA's Glenn Research Center along with ASM International and Granta Design, has led the development and release of the revolutionary new GRANTA Material Intelligence (MI) software platform (www.grantadesign.com), a state-of-the-art tool for managing the life cycle of materials information, from the testing machine to the design engineer's desktop. This comprehensive materials information management system offers a series of powerful software tools to help companies control, analyze, and manage all aspects of the materials data life cycle. The Material Strategy Software Consortium (MSSC) also recently released CES Selector, a PC software application that offers advanced graphical analysis of materials data, plus specialist ecodesign and modeling tools, in support of materials selection and substitution decisions. GRANTA MI and CES Selector provide the data that companies need, when they need it, in the format that they require, saving time and money and increasing competitiveness. Experience the difference (as numerous world-leading, member organizations have) that best-in-class material information software can make to your bottom line.

BENEFITS

These powerful design and analysis tools provide the following benefits:

- Ensure that designers have the right data at the right time in the right format
- Integrate materials information management with the Product Life Management (PLM) process, saving designers time in getting the materials data that they need
- Control and manage testing and quality assurance data to increase efficiency/competitiveness and protect corporate knowledge
- Apply materials information to optimize materials strategy (e.g., to support cost control or quality initiatives)
- Help to ensure regulatory compliance (e.g., with EuP, RoHS, and REACH legislation)



APPLICATIONS

GRANTA MI

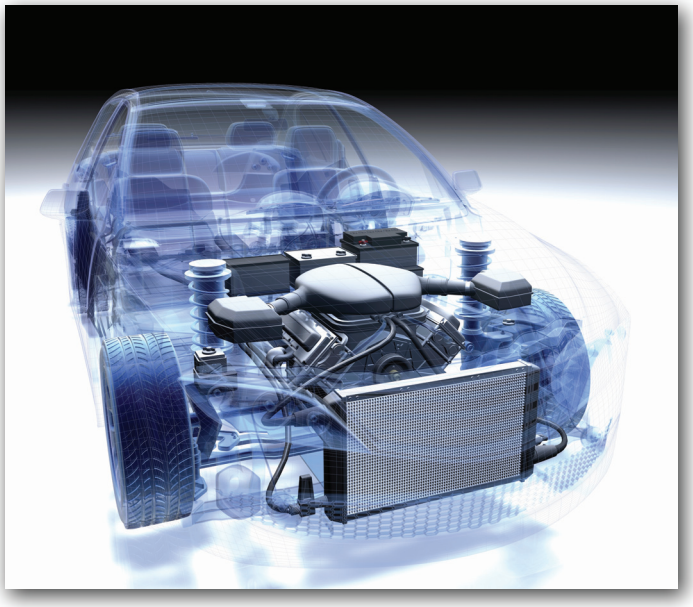
- Implement best practices in materials database management
  - Capture, analyze, and manage all materials in a single, searchable database
- Enable critical materials and manufacturing choices in engineering enterprises
  - Optimize design
  - Reduce cost
  - Avoid risk due to restricted substances

CES Selector

- Helps in selecting materials and alternatives
- Considers sustainability early in the design process
- Visualizes property space to guide development plans

HOW IT WORKS

NASA Glenn Research Center uses GRANTA MI to handle its materials information storage needs for composites. GRANTA MI allows NASA to create a central engineering information database that not only contains typical material property information but also entire response histories (e.g., tensile, creep, relaxation, and cyclic curves) of the associated variables. One of the key capabilities of GRANTA MI is its ability to capture the fundamental multiaxial response data with their full pedigrees (e.g., constituent chemistry, microstructure, processing, testing information, laminate/woven architecture, etc.) and application potential of a given materials system.



WHY IT IS BETTER

The system's main benefits for NASA are the significant time and cost savings and the traceability of material data, including their full pedigrees. The system also links supplemental information through a comprehensive, integrated approach that saves valuable corporate knowledge within the system. Glenn has implemented GRANTA MI to capture, analyze, and share both test data and external reference data. The software enables more sophisticated constitutive modeling and creates an information resource that can support new or refined models and analysis tools in the future, without the need to repeat expensive tests. GRANTA MI has helped NASA streamline its research and design processes by providing a single integrated system for managing materials data.

PARTNERING OPPORTUNITIES

We welcome industry partners to learn more about the following consortiums:

Material Data Management Consortium
The Material Data Management Consortium is a unique collaborative project focused on developing and applying software to manage mission-critical materials data in the aerospace, defense, and energy sectors.

Material Strategy Software Consortium
The Materials Strategy Software Consortium is a collaborative project that defines and applies new software to manage materials data and meet the challenges of material selection, substitution, and cost optimization. Benefits include reducing overall manufacturing costs, mitigating the risks associated with global engineering and improving product quality.

Environmental Materials Information Technology Consortium
The Environmental Materials Information Technology Consortium is a collaborative project that develops and applies materials information technology solutions to assist design around environmental constraints.

Consortium membership is open to all qualifying organizations who utilize the above software tools. Membership provides significant return on investment due to the ability to influence the direction of software development, networking opportunities, and collaborative nature of members.

FOR MORE INFORMATION

For more information about this and other technology licensing opportunities, please contact

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