2004 Technologies

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Engineering Directorate
Marshall Space Flight Center
Huntsville, Alabama

Introductory Comment

Dear Reader,

The Engineering Directorate (ED), as part of its strategy of "creating new and enabling technologies that advance its customers' visions, meet their goals, and enhance U.S. competitiveness," has focused a portion of its investment portfolio into five basic technology areas in which the Directorate maintains a particularly strong capability and which are deemed critical to its customers. These technology thrust areas, consisting of Advanced Avionics Architectures, Advanced Cryotanks, Advanced Manufacturing, Advanced Structures and Materials, and Space Environmental Effects, represent crosscutting, high-impact, and high-value investments for ED customers, and development activities within the Directorate in support of these disciplines are often emphasized.

This publication, structured around these technology thrusts, highlights some of the ongoing technology development efforts that reflect both the talent of the ED workforce and the capabilities of its facilities. Many of these efforts are funded through in-house projects, such as the Center Director's Discretionary Fund (CDDF), and as such, they represent a commitment by ED to develop new technologies to significantly enhance its capability in providing world-class services to its customers.

John W. Kilpatrick
Director
Engineering Directorate

Contents

Advanced Avionics Architecture (A³)

The Thrust Area of A³ is designed to develop next generation avionics solutions for space transportation systems, space exploration systems, and scientific research. This will be accomplished by using and integrating forward-reaching design methods, tools, hardware implementations, and software systems to develop these solutions. The ability to achieve these goals relies primarily upon the extensive, proven expertise of ED's Avionics Department.

The A³ Thrust Area will emphasize the following areas:

- Automated Rendezvous and Docking.
- Scaleable, Fault-tolerant, Intelligent Network of Transducers (SFINX).
- Integrated Interferometric Fiber Optic Gyroscope.
- Smart Structures.
- Advanced Computing Technology Applications.

ENGINEERING DIRECTORATE

Marshall Space Flight Center
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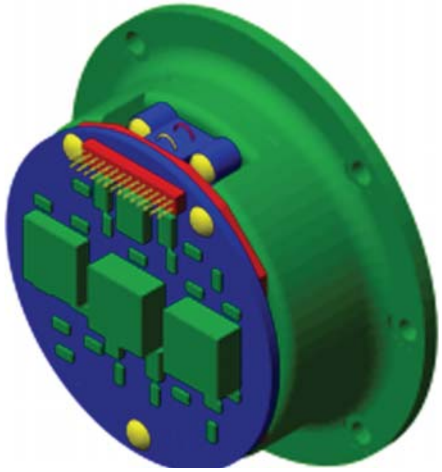
Advanced Sensor Concepts for General Avionics Applications

Benefits

- Produces conventional resolver signals.
- High-quality sensor information.
- Full 360-degree range.
- Small package at a low cost.
- Low rotary inertia.
- Multiple output compatibility possible with internal signal- conditioning electronics.
- Continuous absolute output without discrete jumps as with encoders.
- Electrified redundancy achieved with minimal volume or cost impact.
- This technology can be used in any rotational measurement application including many commercial applications:
  - Printers, photocopiers, and fax machines.
  - Electric motors.
  - Robotics.
  - Medical scanners.
  - Antilock brake systems.
  - Industrial manufacturing equipment.



Point of Contact
Dean Alhorn/ED17
Phone: 256–544–9093
Email: dean.alhorn@nasa.gov

Objective

The objective of this effort is to enhance the viability of the rotary position sensor technology for the commercial sector and to develop advanced concepts into new and useful products for NASA, the aerospace community, and general commercial interests.

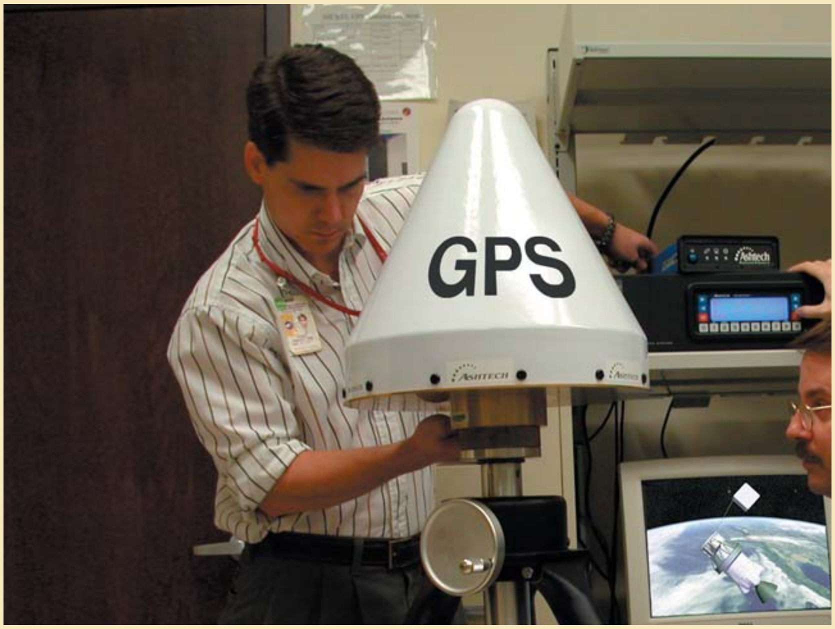
Approach

This technology has been developed in an effort to reduce the size of microgravity vibration isolation systems. The technology can be configured as a rotary position sensor, similar to conventional resolvers, but it uses a different concept for sensing rotary position. The sensor unit also can incorporate signal-conditioning electronics into the housing body to develop the desired output (e.g., analog output of rotary position, absolute encoder outputs, incremental encoder outputs with or without index, R–S485 buffered outputs). The resulting sensor technology has several advantages over conventional means of sensing rotary position. The sensor measures absolute position over the full 360 degrees of rotation and can be miniaturized to fit into various applications. The design can be configured in slip-ring or brushless versions and can easily provide electrically redundant signals. The technology is immune to permanent and alternating magnetic fields, which aids in accuracy. The effort will include the design and manufacture of prototypes and technology demonstration units of the sensors. The resulting products will achieve a reliability and ruggedness for linear position sensors that currently does not exist.

Deliverables

- Develop three concepts into patent disclosures.
- Design prototypes of two new sensor concepts.
- Refine current rotary position sensor patent and produce patent disclosure.
- Manufacture new sensor prototypes and test.

Orbital GPS Health Management



Objective

The objective of this effort is to examine the increase in navigational reliability and accuracy for a launch vehicle or satellite that incorporates a global positioning system (GPS) receiver using the Wide Area Augmentation System (WAAS) corrections and health alerts. The effort will investigate the orbital GPS reliability and accuracy synergistically by combining two GPS technologies: the Federal Aviation Administration (FAA) WAAS and Receiver Autonomous Integrity Monitoring (RAIM). The effort will investigate what can be done in real time, on orbit, using a system originally designed for aircraft. Europe and Japan have a WAAS-compatible system that will also be investigated as an aid to the receiver.

Approach

The investigation plan is to use existing laboratory GPS simulators with WAAS capabilities to test receivers capable of both WAAS and orbital operations—i.e., without International Traffic in Arms Regulations (ITAR) altitude or speed limit restrictions. The initial testing of the receiver will use the investigation of the increase in static accuracy using WAAS signals with a live sky antenna to validate the simulator.

Benefits

These technologies have never been combined before for orbital or launch application, WAAS corrections, and RAIM testing using real hardware. Currently, Jet Propulsion Laboratory (JPL) utilizes their worldwide Differential Golbal Positioning System for orbital corrections, but that requires special hardware to receive and process the information. This effort should be of benefit to any vehicle or experiment that utilizes GPS for navigation. Also, knowledge of and reaction to unhealthy GPS satellites should mitigate the negative effect so it is unnoticeable to the eye of an observer. The result of this could be less anxiety in the docking of spacecraft and greater life for satellites, since their launchers would have more knowledge of their injection location. It is anticipated that there will be a multiple-meter reduction in navigation uncertainty. This effort may result in novel algorithms or procedures for determining orbital GPS reliability.

Deliverables

- Orbital Accuracy Increase with WAAS Test Report.
- Orbital WAAS and RAIM Reliability Test Report.

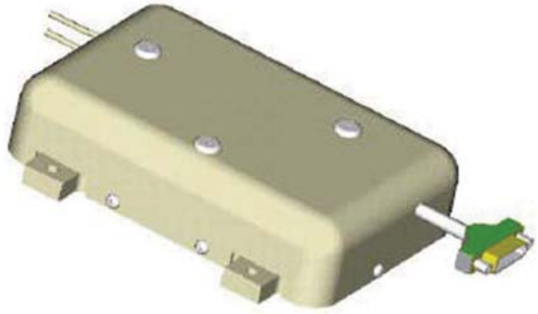
Point of Contact

Ken Schrock/ED18
Phone: 256–544–1460
Email: ken.schrock@nasa.gov

Programmable Low-power, High-voltage Power Supply With Fast Rise Time

Benefits

Marshall Space Flight Center (MSFC) has already designed an open loop high-voltage power supply with rise/fall times less than 100 μs, and through such capabilities is being acknowledged as a leader in the development of new power supplies. Indeed, the need for the proposed design has already been identified on several future flight projects. It is anticipated that this state-of-the-art development will lead to a potential patent and will have possible applications in the area of smart structures.



Objective

The objective of this effort is to develop a low-power, closed-loop, high-voltage power supply with the following capabilities:

- Programmable between 0 V and 1,250 V.
- Rise-time of less than 100 μs.
- Fall-time of less than 100 μs.
- Operational at pressures from a hard vacuum to 1 atmosphere.

Approach

The plan is to design and breadboard a high-voltage power supply and verify that the power supply meets desired output voltage, rise-time, and fall-time requirements. Since size, weight, and efficiency drive the requirements of most payloads, these issues will be emphasized in the design, and the final output will definitely improve the current techniques for packaging high-voltage power supplies. A prototype will be built to verify that all requirements are met.

Deliverables

- This effort will produce a fully functional high voltage power supply fulfilling the desired specifications of the objective. It is also anticipated that this work will lead to a patent opportunity.

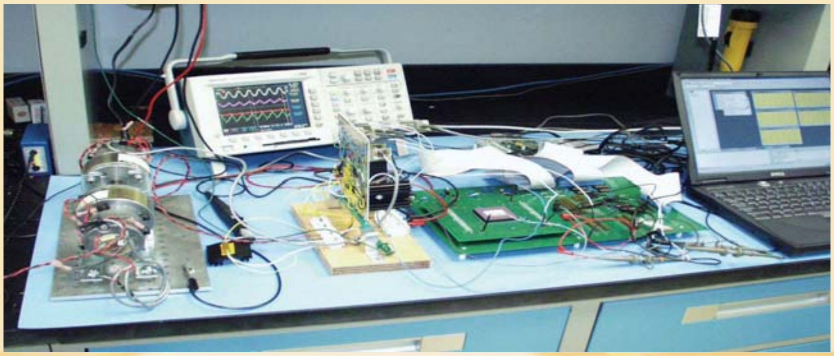
Point of Contact

Douglas Bearden/ED11
Phone: 256–544–3340
Email: doug.bearden@nasa.gov

Hardware Evolution for Configurable Closed-loop Control

Objective

The goal of this effort is the online evolution of closed-loop control structures that can be used in a control system configuration strategy. Specifically, experiments will be designed and executed in which control structures are evolved using an evolutionary algorithm to provide hardware configurations that meet a defined control performance specification. Ultimately, the goal is to provide a framework for the online evolution of closed-loop control structures that can be used in a control system configuration strategy.



Approach

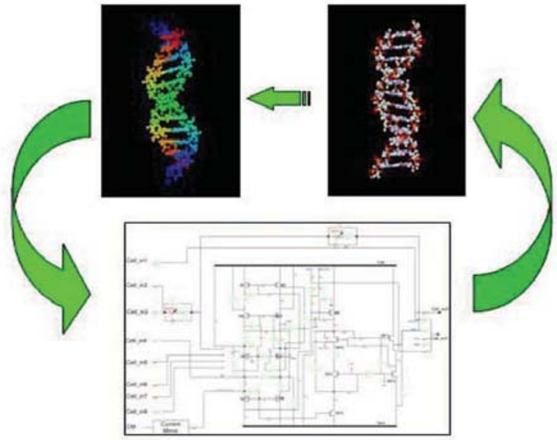
The effort will utilize a reconfigurable programmable circuit device as the hardware medium for implementation of evolved designs. The effort will also utilize established relationships with researchers at the Ames Research Center (ARC) and JPL to provide software and hardware inputs into the basic design. For the experiments, a controller performance goal will be established, and the evolutionary algorithm will start with a population of seed hardware that is loaded on the programmable device being utilized. Through an iterative process, an evolutionary algorithm will evaluate the fitness of hardware designs and modify them in a prescribed manner until the fitness of the population plateaus and the design converges.

Deliverables

- Mixed-signal Controller Evolution.
- Digital Controller Evolution.

Benefits

Currently, the evolution of closed-loop controllers is accomplished in simulation, and no feedback is provided. It is not done in hardware with real dynamic systems, nor in real time. The proposed effort seeks to perform closed-loop controller evolution in hardware with the ultimate goal of producing a system that can evolve controllers online, producing a self-healing system that can reconfigure itself. This effort will apply evolutionary algorithms and hardware evolution in the development of advanced avionics architectures. Long-term benefits of this effort will include novel controller designs resulting in patents, autonomous configuration of controllers, and controller fault tolerance through reconfiguration.



Point of Contact

David Gwaltney/ED17
Phone: 256–544–4231
Email: david.a.gwaltney@nasa.gov

Architecture for a Fault-tolerant Servomotor-driven Smart Controller

Benefits

Fault-tolerant control is needed to reduce system downtime, to improve system performance in the face of component failures, and to provide a wider margin of safety in a controlled system. This effort will provide the design of electronics for the controller of a servomotor-driven actuator that can provide enhanced reliability through redundant capability, voting, and fault-tolerant control approaches. This task will improve the state-of-the-art by leveraging recent advances in smart transducer concepts due to Institute of Electrical and Electronic Engineers (IEEE) standards. The benefits of this technology include actuator intelligence for improved command and control capabilities, enhanced reliability through scaleable redundancy, and fault detection and isolation (FDI) and fault tolerance control.

Point of Contact

David Gwaltney/ED17
Phone: 256–544–4231
Email: david.a.gwaltney@nasa.gov

Objective

The objective of this effort is to design an architecture for a smart actuator suitable for inclusion in a network of fault-tolerant transducers as a part of a spacecraft avionics system. The secondary focus will be to investigate fault detection techniques suitable for use in fault-tolerant control approaches. Investigations will be conducted to determine an appropriate hard, soft, or hybrid technique for fault detection and fault-tolerant control strategies.

Approach

The requirements for the controller electronics are based on specifications developed for the Scaleable Fault-tolerant Intelligent Network of X(trans)ducers (SFINX), an endeavor to demonstrate an advanced avionics architecture employing a two-wire network between a network capable application processor (NCAP) and transducers, but which did not include a motion control actuator. This effort will provide a design for electronics to be part of a servomotor-driven smart actuator that can support fault tolerance through redundant capability, voting, and fault-tolerant control approaches. The effort will focus on the development of unique hardware components for fault-tolerant control of the Brushless DC (BLDC) motor.

Deliverables

- Embedded control module that supports the deployment of a fault-tolerant, real-time distributed network of sensors and actuators by providing enhanced reliability through:
  - – Fail silent control modules.
  - – Scalable redundancy.
  - – FDI.
  - – Fault-tolerant control.
- Actuator intelligence for improved command and control capabilities.
- Flexibility to support motors with standard and redundant windings.
- Hardware demonstration.

Flight Critical Hardware Voting Development

Objective

The objective of this effort is:

- To develop techniques and hardware to perform cross-link voting, which supports the SFINX architecture and fills an instrumentation and control industry gap.
- To provide basic building blocks that will meet NASA flight critical specifications for redundancy management.
- To build and demonstrate the capabilities of these hardware-voting components.
- To explore intelligent methods that ensure correct sensor or component placement and cabling integrity.

These objectives will be accomplished using requirements developed in the SFINX program, which evaluated several needed voting methods. This effort catalogs voting methods and defines the common components and parts for single- to quad-redundant avionics systems. These components will be built and tested to prove their functionality and capabilities.

Approach

An object-oriented hardware voter design is planned using the requirements developed in the SFINX program. In SFINX, several types of voting methods were identified as needed. These techniques, defined by the project's redundancy management expertise, are needed by both NASA and the instrumentation and control industry. This effort will catalog these methods and define the common components and parts for single to quad-redundant systems. These components will then be built and tested to prove their functionality and capabilities. Finally, documentation will be provided on the relevant component technologies.

Deliverables

- Plug-and-play hardware.
- Cross-channel voters for automated, high-speed redundancy management.

Benefits

This concept will provide key building blocks to the avionics and instrumentation and control community. A high demand is anticipated from the safety-critical instrumentation and controls industry for these voting components, which will simplify redundancy management and will be applicable in many industrial applications. This effort will benefit many space applications designing or using flight-grade instrumentation by lowering the cost of control systems. It also enables new sources due to Government nonproprietary redundancy management solutions.

Point of Contact

Anthony Kelley/ED12
Phone: 256–544–7646
Email: anthony.r.kelley@nasa.gov

Soft Computing for Engine Control

Benefits

New insight will be gained into the behavior of Soft Computing Technologies (SCT) in the rocket engine control environment. The methodology created will provide a new approach to the field of employing SCT in rapid response engine control systems for future vehicles. Furthermore, the use of SCT is expected to improve:

- Software management.
- Software development time.
- Software maintenance.
- Processor execution fault tolerance and mitigation.
- Nonlinear control in power level transitions.

It is expected that this effort will demonstrate that by employing SCT, issues in quality and reliability, and ultimately safety, of the overall scheme of engine controller development can be further improved.

Point of Contact

Luis Trevino/ED14
Phone: 256–544–1233
Email: luis.c.trevino@nasa.gov

Objective

The objective to this effort is to investigate and demonstrate how the application of SCT in the development of a qualitative and reliable engine control system (QRECS) can improve overall vehicle system safety, reliability, and robust rocket engine performance. Primary objectives in this effort for developing QRECS include addressing the issues of improving software management, development time, implementation, processor execution, and sustaining engineering for all phases of rocket engine operations (i.e., prestart and engine prep, ignition start, start-up sequence, mainstage, nonlinear power level transitions, and shutdown). This task will provide alternative design choices for control, implementation, performance, and sustaining engineering, all relative to addressing reliability. This effort will utilize existing knowledge in the fields of rocket engine propulsion on a system level, software engineering for embedded systems, and soft computing technologies (i.e., neural networks, fuzzy logic, data mining, and Bayesian belief networks).

Approach

The engine controller will be designed and developed using all relevant controller information and design variables to generate a training database. For the control functions of mainstage control, fault detection, and mitigation, neural networks will be utilized and a back-propagation algorithm tool used to develop the individual neural network modules. In parallel with this activity, an object-oriented analysis will be used for design and development of the overall control architecture, interfaces, and software executive. Testing will utilize all capabilities in the MC–1/MSFC Avionics & Software Test-bed (MAST Lab), and verifying all objectives are satisfied. The controller will be configured to active mode and tested. Hot-fire testing of the system will be evaluated for integration into existing rocket engine programs.

Deliverables

- Engine Control Software based on soft computing technologies. Test-bed engine is the MAST Lab environment.
- Process for implementing soft computing technologies for engine control.

Redundant Serial Interface Microcontroller

Objective

The objective of this effort is to develop triple modular redundancy (TMR) techniques for use on emerging high-speed serial interface microchips to demonstrate that TMR techniques applied to space flight system designs would have considerable reliability and performance benefits over standard parallel bus interfaces. The effort will 1) evaluate redundancy techniques for application on serial interfaces, 2) develop TMR techniques for use in serial interface applications, and 3) develop and demonstrate a TMR high-speed serial interface microcontroller system. The resulting microcontroller system would have applications in Integrated Avionics/Vehicle Health Management where area, power, and uninterrupted loss of data are vital.

Approach

After an evaluation phase, a design will be simulated using in-house simulation tools. After proof of simulation, a prototype system will be built and tested. The development systems will consist of a small, low-power, redundant microcontroller system for use in mid- to low-level systems. Testing will consist of producing multiple single failures and monitoring for failures. This system would maintain triple redundancy through any single microcontroller fault. After fault detection, the failed controller will be brought offline and self-tested while a standby microcontroller replaces its function. This would result in continual triple module redundancy throughout the test.

Deliverables

A prototype system utilizing TMR techniques that will:

- Demonstrate the feasibility of TMR applications on serial interfaces.
- Give a comparison of the potential power and logic savings along with increased reliability from using redundant serial interfaces.

Benefits

Triple redundancy is of particular benefit to spacecraft applications in high radiation environments using newer commercial off-the-shelf (COTS) technology microchips where single point failures are more common. Adapting these newer technologies to a radiation environment and the radiation testing of parts is both expensive and time-consuming. Serial interfaces have many benefits over parallel communication. Older triple module redundancy techniques for microprocessors and microcontrollers perform logic checks on the parallel interface, which consists of address, data, and relevant control logic signals. Many newer microchips are incorporating high-speed serial interfaces, which consist of data, clock, and relevant control signals. The standard parallel interface can easily be over fifty lines, whereas a serial interface would typically be less than five. The logic and power savings of utilizing TMR on high-speed serial interfaces over parallel interfaces would be considerable. From a manufacturing standpoint, serial interfaces are easier to route and produce by nature of having considerably fewer traces.

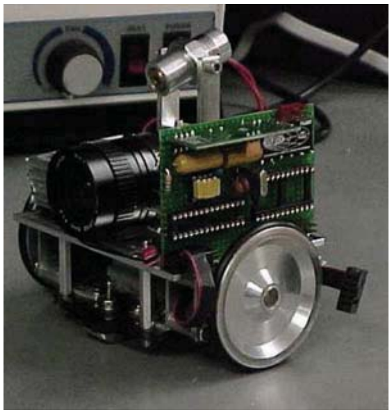
Point of Contact

Lisa Coe/ED13
Phone: 256–544–8588
Email: lisa.d.coe@nasa.gov

Miniature Inspection System Technologies Development for Confined Spaces

Benefits

The ultimate applications of these technologies will solve a family of Integrated Vehicle Health Management (IVHM) challenges, inspection in confined spaces. The benefits include improved safety, reliability, and maintainability of space transportation system vehicles by detection of foreign object debris in propulsion systems, capability to locate materials/structures surface anomalies indicating hazardous conditions, and use of highly structured robotic operations to avoid human errors. Direct visual (including an extended spectrum) detection and/or confirmation of sensor indications of vehicle status will not only enhance operational confidence, but also, by codesign of vehicle systems and robot inspectors, alleviate costs associated with human/vehicle interactions such as access panels and Occupational Safety and Health Administration (OSHA) standards.



Objective

The objective of this effort is to develop and demonstrate technologies for miniature, semiautonomous/autonomous internal inspection of current and future MSFC-developed space transportation systems. The proposed task will include development of technology areas including: (1) micromotor control, (2) end effectors, (3) microimaging systems, and (4) simulation software. The end result of this effort will be the simulation of a system incorporating the micromotor controller, end effectors, and the microimaging system. A second objective of this proposal is to demonstrate selected robotic inspection technologies operating in a physical environment simulating a vehicle system of interest. Use of nonflight hardware for this demonstration will be assessed.

Approach

The approach pursued by this effort includes continued discussion with customers to identify confined space inspection requirements, such as feed-lines and other cylindrical spaces, with emphasis on the inspection of tubes with right angles. The results of this initial work will be precise requirements definition and a miniature parts list. The design and fabrication of scaled technologies including an imaging system, micromotor controller, and end effector will proceed. Software (pattern recognition) algorithms will be developed by leveraging previous research involving vision system development. The results of the end technology will be simulated and demonstrated.

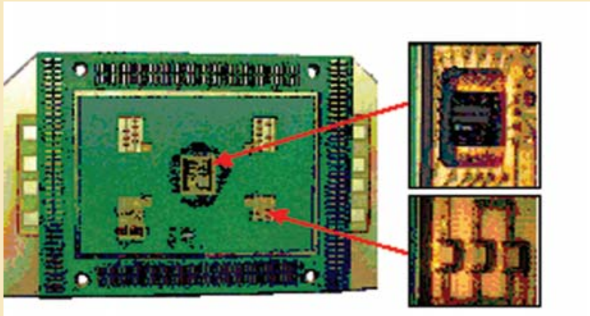
Deliverables

- The simulation of a system incorporating a micromotor controller, end effector, and the microimaging system.
- The demonstration of robotic inspection technologies operating in a physical environment simulating a vehicle system of interest.

Point of Contact

Jeri Briscoe/ED13
Phone: 256–544–3480
Email: jeri.m.briscoe@nasa.gov

Development of Embedded Packaging Assemblies Using Silicon Die and Passive Components Embedded in Copper/Laminate Substrates



Objective

The objective of this effort is to determine if embedded packaging of silicon die and passive components in copper/laminate substrates has the robustness to survive in a space environment, and to determine what the predominant failure mode might be. The emerging technology of embedding active and passive electronic parts within a printed wiring board rather than mounting them to the surface of the board, as is the current practice, offers a significant potential for reducing size and weight. We envision taking this technology a step further and mounting the semiconductor die directly onto a metal core within the circuit board and interconnecting them by wire bonding to the circuit board. By eliminating the intermediate die packaging step we can further reduce size and weight, eliminate or greatly reduce the number of solder joints, and reduce the temperature rise in the circuit junctions within the die.

Approach

The plan for this effort is to: 1) design an embedded circuitry printed wiring assembly using die with daisy-chained connections for monitoring the circuits, 2) fabricate these assemblies in two configurations: bare die and wire bonds with an intermediate coating and coated die and wire bonds with a silicone gel and copper cap, 3) perform extended thermal cycle testing from –55 °C to 125 °C on the assemblies to assess robustness of the wire bonds and the effect on them of the subsequent processing steps, and 4) perform destructive physical analysis (DPA) on pulled samples periodically throughout the cycling to assess the condition of the wire bonds.

Deliverables

- Embedded circuitry printed wiring assembly environmentally tested and evaluated for robustness.

Benefits

- Decreased signal length resulting in increased circuit speed.
- Wafer-level known-good-die procurements eliminating the need for screening.
- One-location die packaging for devices used providing consistent process control.
- Increased reliability by elimination of one-third of the electrical interconnections.
- Elimination of solder joints (traditionally, one of the weakest links in the avionics reliability).
- Increase in the functional density of the circuit boards.
- Elimination of all coplanarity requirements for the circuit boards.
- Elimination of the cleaning problems and underfill requirements of area array packages.
- Assured visual inspectability of all electrical interconnections.
- Reduced overall package weight and volume by 400 percent to 600 percent.
- Possible elimination of housing.
- Significantly increased ability to dissipate heat.
- Internal damping of circuit elements providing high vibration and shock tolerance.
- Electromagnetic interference (EMI)/ electromagnetic compatability (EMC) shielding and radiation total dose reduction.
- Closer front-end coordination among circuit designers and packaging designers and electrical, electronic, and electromagnetic (EEE) parts engineering.

Point of Contact

Mike Selby/ED16
Phone: 256–544–3716
Email: Micheal.W.Selby@nasa.gov

Polymer Thin Film Sensors for Health Management Applications

Benefits

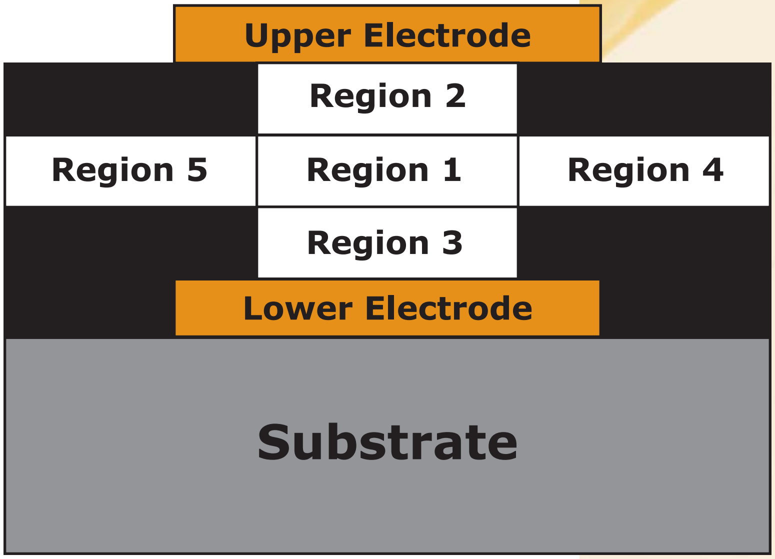
Polymer thin films are a promising class of sensor materials that are compact in volume, negligible in weight as compared to the sensed component, and extremely low-power. These qualities make them optimum for use as health management sensors for space vehicles, where large numbers of sensors are required in a variety of locations and environments to monitor every system component for enhanced vehicle safety, improved vehicle performance, and reduced vehicle maintenance. The improved knowledge of the poling process and thermal properties enables the fabrication of more efficient, higher-sensitivity, and more compact sensors available for various health monitoring applications.

Objective

The objective of this effort is to evaluate electrical poling (dipole orientation) and thermal properties of polymer thin films for application as conformal health management sensors and to develop a polymer thin film modulator for application in low-power optical gyroscopes and communication systems.

Approach

Polymer film sensing properties are directly related to their polarizability, which is the source of their piezoelectric and nonlinear optical properties. Thus, understanding polymer thin film polarization properties is essential to their application in space vehicle health management and other avionic systems. This effort seeks to determine the basic poling mechanisms for polymer films and determine the poling conditions necessary to achieve optimal operation. Thermally stimulated current studies will be conducted to determine the basic molecular alignment mechanisms, and this information will be used to develop the optimal poling characteristics. Low voltage operation and high thermal stability are the desired traits for a good health management sensor, and different films will be investigated to determine their suitability for space application.



Deliverables

- Database of poling properties as well as thermal stability and low-voltage properties of selected polyimide materials suitable for the development of polymer thin film sensors for space applications.

Point of Contact

Mike Watson/ED12
Phone: 256–544–3186
Email: Michael.D.Watson@nasa.gov

Using Software Complexity in Flight Software Defect Analysis and Prevention

Objective

The objective of this effort is to determine if a thorough insight into software quality can be gained through module-by-module metric calculations that can help us identify where a program is more empirically likely to contain errors. More specifically, it will explore the relationship between software complexity and software defects by examining the complexity of each software module and comparing it to the number of software defects that have been identified for that module using all available resources. This effort will minimally address the following questions: 1) Can we use software complexity measurements to help us assess the quality of the flight software modules, 2) How does software complexity drive software testing and maintenance costs, and 3) Can we accurately measure risk and improve software quality while still meeting critical deadlines using the software complexity measures?

Approach

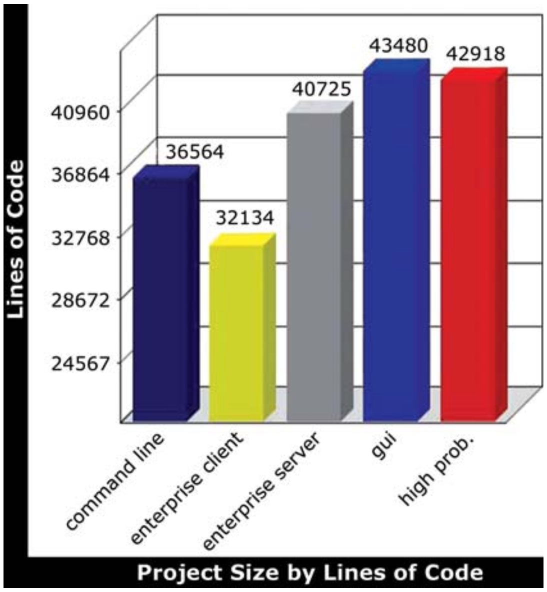
The approach pursued in this effort will be to utilize a COTS industry standard software complexity analysis tool suite to perform a thorough analysis of selected flight software tools. A comprehensive typification, via analysis, of the database of software defects for in-house developed software projects will be performed, and correlative examinations will be made between the tool results and the software defects database as well as the time spent in software test/maintenance. The results will be used to update current in-house software insight review processes and software development processes.

Deliverables

- This endeavor would provide for early anomaly detection leading to possible prevention of major subsystem problems. It will provide predictive and diagnostic debug capabilites to be better utilized throughout the software life cycle.

Benefits

All NASA projects involving flight software would benefit from this effort, since better insight would be gained into the process of software development, defect analysis, and prevention. The methodology proposed would also further enable the early detection of complex code and, thus, provide a more efficient mechanism to focus insight review resources and software testing resources appropriately. This endeavor would certainly better provide for early anomaly detection, thus leading to possible prevention of major system problems. It is also anticipated that the results of this effort would provide predictive and diagnostic debut capabilities to be better utilized throughout the software life cycle by conserving resources for lower-level software issues. In the end, all products of this effort would provide more data for process improvement efforts and improve our defect tracking metrics program.



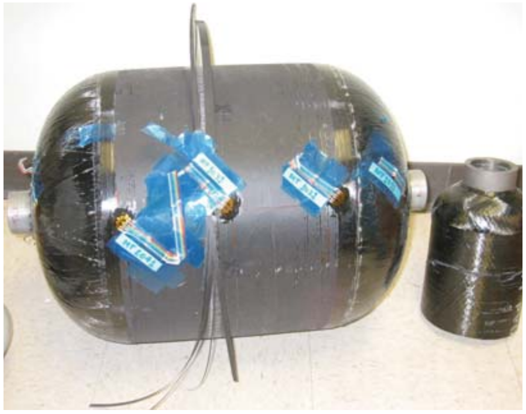
Point of Contact

Will Crisp/ED14
Phone: 256–961–0211
Email: Will.Crisp@nasa.gov

Embedded Acoustic Emission Sensor for Carbon Fiber Composites

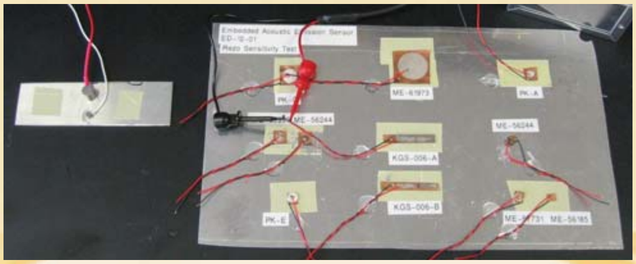
Benefits

Acoustic emission nondestructive testing has been used in numerous applications for providing quality assurance for structural components. Recently, the aerospace industry has begun to use acoustic emission for monitoring components in flight as well as during test. Research is ongoing to develop sheet-type sensing systems that can be embedded in a composite as it is cured and can be used in an active mode for structural health monitoring and for impact detection. However, such sensors are not now designed for passive acoustic emission testing and for detecting the microscopic origins of failure in a composite structure. By incorporating a large array of embedded sensors, such as planned for this effort, damage propagation can be detected long before it becomes critical, allowing for actions to be taken to relieve the stress or fix the problem.



Objective

The objective of this effort is to develop a small, inexpensive, lightweight sensor which can be mounted on, or embedded into, structures during fabrication and is compatible with commercial acoustic emission instrumentation systems capable of detecting active microdamage propagations in composite structures. The sensor will measure the acoustic emission activity of the composite material as it is stressed, providing a means to monitor the health of the structure. The sensor will be designed to record failure modes, including fiber breakage, delamination, resin microcracking, fiber-matrix debonding, fiber splitting, etc. The sensor will be designed to withstand the temperature and pressure of composite curing, as much as 350 ˚F and 100 psig, as well as operate at cryogenic temperatures below -400 ˚F.



Approach

The sensor will use a common tape lead for delivering the amplifier DC power and the high-frequency acoustic emission (AE) output to external AE instrumentation. The performance of these sensors will be compared to existing commercial units based upon weight, cost, size, sensitivity, frequency response, durability, and ability to be integrated in a composite structure. Methods to integrate and embed the sensors and associated low-noise electronics into or onto the composite laminate will be investigated, with miniaturization being a prime focus. Components chosen for research will be mounted on a substrate and incorporated into a composite structure for testing.

Deliverables

- Lightweight embeddable acoustic emission sensor with miniaturized electronics for use in structural health monitoring.

Point of Contact

W.T. Powers/ED12
Phone: 256–544–3452
Email: w.t.powers@nasa.gov

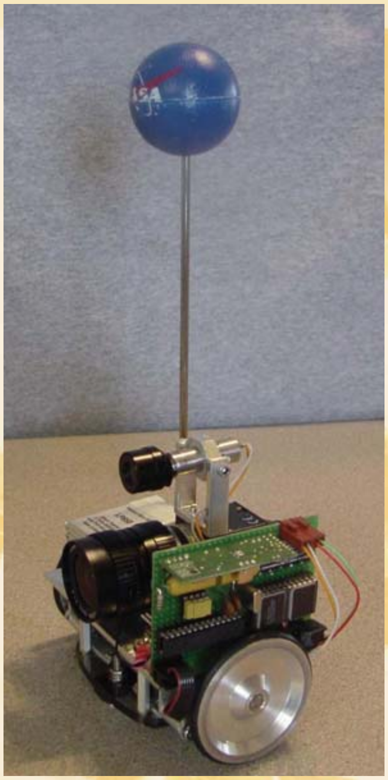
Vision System Development for Miniaturization Robotics

Objective

- Primary Objective: Develop a test platform for the development, implementation, and evaluation of advanced vision systems to perform metrology and robotic vision.
- Secondary Objective: Investigate the unconventional use of traditional components to provide a simplified distance approximation device (DAD) that can be miniaturized and used for robotic vision.

Approach

A test platform has been developed employing a stereographic vision capability in order to evaluate advanced vision systems. The test platform design lends itself to using traditional hardware and mapping techniques to develop an advanced algorithm for distance measurement. Different approaches were investigated to determine image plane-to-object distance. Specialized optics, filters, and image processing techniques were used to minimize adverse lighting conditions and reflections. A novel method for approximating distance using one camera and a laser diode was investigated. The DAD was assembled and an algorithm developed. Considerations for miniaturization were also examined. The final design was miniaturized, mounted onto a miniature (7″ × 7″ × 4″) robot, and will be demonstrated in a simulated environment.



Deliverables

- A test platform for the development, implementation, and evaluation of advanced vision systems to perform metrology and robotic vision.
- A prototype miniaturized distance approximation device to provide accurate distance information for guidance of mobile vehicle health monitoring systems.

Benefits

- This effort provides an increased capability to contribute to the Agencywide development of inspection/maintenance robots and enhanced customer support in the areas of imaging and optics.
- The development of a simplified vision system for miniature robots will enable inspection in areas inaccessible to tethered robots, such as Space Shuttle Main Engine (SSME) or hazardous environments.
- This research will result in the improved capabilities in image processing, novel lighting techniques, imaging system design, optics, and robotics.

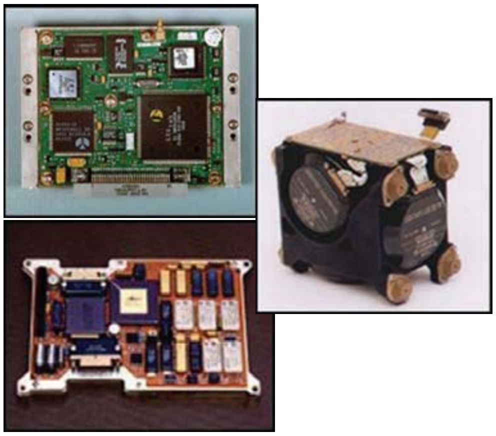
Point of Contact

Jeri M. Briscoe/ED12
Phone: 256–544–3480
Email: jeri.m.briscoe@nasa.gov

Low-cost Avionics for X Vehicles

Benefits

Avionics costs have been a significant factor in the failure to achieve an in-house design for an advanced launch vehicle that would significantly reduce launch costs. As a result of previous ED support to the X–33 program, the Avionics Department now has a high fidelity test-bed for X-vehicle avionics that is fully operational, and this capability is available to support the development and performance evaluation of lightweight, low-cost avionics systems using operational avionics hardware from military programs. This effort could result in the identification of low-cost avionics hardware with direct application to an avionics design of an advanced vehicle.

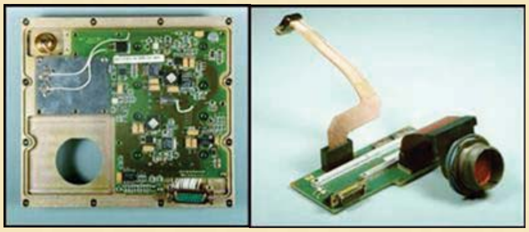


Point of Contact

Fred Roe/ED19
Phone: 256–544–3512
Email: fred.d.roe@nasa.gov

Objective

The purpose of this effort is to demonstrate the use of military avionics technology to control an X vehicle. Suitable existing Army avionics systems will be brought to the MAST Laboratory for integration into X Vehicle simulations and for demonstration in a real-time hardware-in-loop simulation of an X-Vehicle Inertial Navigation Unit/Global Positioning System (INU/GPS) testing that was conducted for Lockheed/Allied Signal under a previous X–33 task. The performance of the selected systems will be evaluated.



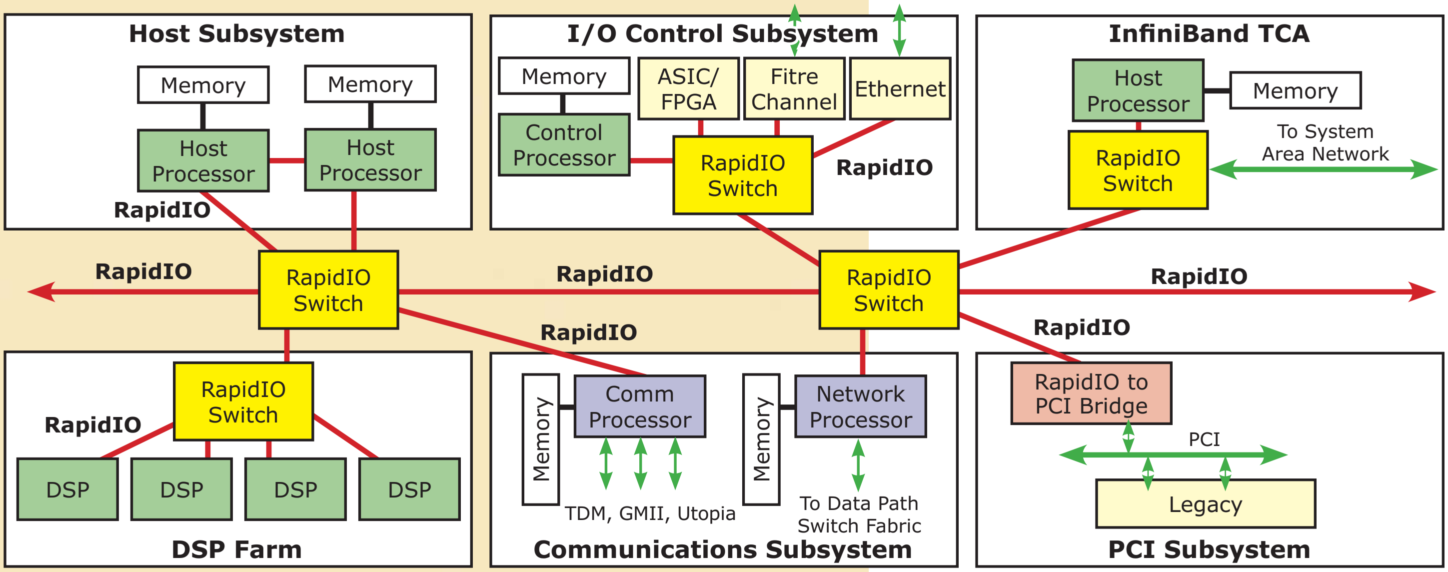
Approach

This effort will utilize a teaming arrangement with Army Aviation and Missile Command (AMCOM) technical expertise to identify candidate INU/GPS systems that have potential for control of an X-type vehicle. The systems would be reviewed for cost, performance requirements, and possibility of space qualification. Once a candidate system has been selected, it, along with supporting hardware, would be brought into the MAST laboratory for performance evaluation and demonstration. The results will be compared to systems previously developed for use with an X-vehicle. Follow-on activities will include navigation testing in a mobile test-bed and flight testing as an MSFC flight experiment on an X-vehicle using the selected system to replace existing flight systems.

Deliverables

- INU/GPS system, with space capability, for evaluation in an MSFC test facility.

Modular Avionics Redundancy and Testability Architecture (MARTA)



Objective

The objective of this effort is to develop the emerging field of high-speed serial interconnects to understand how they should be applied in an advanced avionics architecture. In particular, the effort will focus on interconnect and test standards for use in a distributed avionics system. State-of-the-art high-speed serial back-plane technology can reduce avionic weight, power, and complexity, and it can improve reliability. Applying the IEEE Joint Test Action Group (JTAG) test standard to avionics system design will provide a high speed test capability at the board and box level, reduce system check out time, increase reliability, and allow logic and software reconfiguration with avionics in place.

Approach

Following a trade study of the high-speed interconnect schemes available, one will be selected that is well suited both to industry and to space avionics. Using COTS processor boards, as well as current and new design tools and field programmable gate arrays, a custom card will be designed to implement and demonstrate the selected serial back plane standard. This card will utilize the selected high speed interconnect to communicate with the main processor card and perform typical avionics tasks. Further investigations will be performed to determine how to test a system based on the selected interconnect scheme using JTAG boundary scan techniques. Building a prototype that uses the best suited interconnect method will insure that all the details of the interconnect are well understood.

Benefits

High-speed serial switch fabrics are the current state-of-the-art in board and system interconnects. At the same time, JTAG use is increasing as modern electronic systems become more integrated and harder to test. The work proposed in this effort will result in intelligent busses and will improve the capability to build boards and boxes that are highly testable. The output of this work can expand to board-level systems in order to improve system reliability such that if an individual card malfunctions, it will not impact the overall system.

Deliverables

- Interconnect and testability trade studies.
- Architecture and logic design.
- COTS/custom cards ready for test.
- Final reports and prototype.

Point of Contact

Kosta Varnavas/ED13
Phone: 256–544–2638
Email: kosta.varnavas@nasa.gov

Advanced Cryotanks

This ED Technology Thrust Area seeks to advance NASA's expertise and capabilities by developing and demonstrating the technologies needed for advanced integrated cryogenic tanks for Reusable Launch Vehicles, In-space Storage, and other specialized payloads. In doing so we will:

- Mature and integrate the building block set of engineering tools necessary for an Integrated Product Team (IPT) to achieve Technology Readiness Level (TRL) increases as quickly and affordably as possible.
- Identify and facilitate new partnerships with industry, academia, Department of Defense (DOD), and other NASA Centers.
- Invest in infrastructure that bridges the business case gap between fundamental research and TRL 7–9 production.
- Provide a technology repository for the National cryotank community.

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Advancement of Composite Tank Technology for New Upper-stage Launch Vehicles

Benefits

Many new upper-stage launch vehicles are considering hypergolics, hydrogen peroxide, liquid oxygen, liquid hydrogen, and kerosene for fuels and oxidizers. They all rely on much lighter storage tanks that are compatible with those fluids. There have been some shortcomings with some of the tanks on current programs that might jeopardize their success. There is a strong need for a new series of composite tanks and test data to validate their design. Another need is a test-bed of tank technologies to try new concepts and provide information to assist mainstream projects. The results of this effort will greatly enhance the understanding of manufacturability of the tanks and how they can be applied to various vehicles. It will generate a synergistic relationship between several organizations and advance the progress of current programs. It will result in a better understanding of testing and inspection as well as material and process compatibility.

Point of Contact

Tom Delay/ED34
Phone: 256–544–1131
Email: Tom.Delay@nasa.gov

Objective

The purpose of this effort is to advance the state-of-the-art in composite tank technology by producing innovative composite tank concepts that are applicable to the new launch vehicle concepts and satellites. The tanks may contain fuels and/or oxidizers (ambient and cryogenic temperatures) or other fluids and pressurant gases as needed.

Approach

This effort will produce a series of composite tanks that can be utilized by NASA, JPL, and DOD programs and show promise for commercial non-aerospace applications. The approach is to develop innovations which improve the performance of the vessels. The innovations include: novel tooling methods, alternate composite material development, ultralight tank liner development, and creative tank design that is application specific. A "building block" approach will be taken to demonstrate new technologies on smaller prototype vessels. Successfully tested vessels are later produced to demonstrate scalability and performance enhancements are added.

Deliverables

- New designs, materials, and manufacturing processes for the application to tanks and pressure vessels needed for upper-stage and in-space vehicle programs.
- Prototype tanks for testing and verification.

Development of Advanced Composite Tanks, Lines and Ducts for Cryogenic Applications in Launch Vehicles Using New Materials and Processes

Objective

The ultimate objective of the proposed work is to develop an all-composite tank suitable for the containment of cryogenic fluids for space and launch vehicles. An additional objective of this effort will be to show how the same technology is applicable to other components such as lines, ducts, and turbopump housings.

Approach

A stepwise building-block approach will be used to demonstrate the vessels. This proposed task will include (1) the evaluation of off-the-shelf and newly developed materials, (2) the formulation of new materials and processes, (3) the fabrication of prototype vessels, and (4) the thorough testing of the tank hardware to demonstrate end-of-life properties. The proposed effort will demonstrate an innovative, yet sensible, approach in the development of an all-composite cryogenic tank technology. Subscale test articles will be produced and tested under relevant environments.

Deliverables

- Subscale test articles produced and tested under relevant environments.
- Generated test data that can be used to boost the confidence in the development of large-scale cryogenic tanks for launch vehicles or smaller vessels needed for in-space fueling depots or satellites.
- Single-walled demonstration vessel ideally suited for the containment of cryogenic fluids.

Benefits

All-composite tanks are not currently in use, and though there have been several attempts to produce them, the technology is still somewhat immature. In this effort, generated test data will be produced that can be used to boost the confidence in the development of large-scale cryogenic tanks for launch vehicles or smaller vessels needed for in-space fueling depots or satellites. The proposed work will result in a single-walled demonstration vessel ideally suited for the containment of cryogenic fluids. Such a vessel is considered to be the first step in producing larger tanks that may involve external loads, and it could be viewed as the inner tank of a dual-walled tank structure. Another result will be the better understanding of material behavior at cryogenic conditions. This understanding of material performance will also be enabling to the development of reliable lined pressure vessels at cryogenic conditions (an area of commercial interest due to the increased need for liquid natural gas and liquid hydrogen for alternate fuel vehicles).

Point of Contact

Tom Delay/ED34
Phone: 256–544–1131
Email: Tom.Delay@nasa.gov

Advanced Manufacturing

The Advanced Manufacturing Thrust Area addresses the research and technology development needs for manufacturing the next generation of reusable space transportation systems, while also building a future manufacturing technology base for NASA and industry. The foundation of this focus area is the NASA National Center for Advanced Manufacturing (NCAM). The NCAM is chartered to provide national leadership to maintain the capabilities necessary for advanced manufacturing of propulsion and launch vehicle systems and to assure NASA's future manufacturing engineering capability. This focus area encompasses process development and advanced manufacturing technologies for aerospace vehicles, structures, and propulsion systems. Within this plan, new and emerging techniques are conceived, evaluated, characterized, and matured for manufacturing and implementation in NASA programs. Investment areas include research and educational projects in association with NCAM, government, academic, and industrial partnerships. Technology areas include:

- Composites (Polymer Matrix Composites (PMC), Ceramic Matrix Composites (CMC), and Metal Matrix Composites (MMC).
- Metals (diagnostics/analysis, alloys, net shape processes, welding).
- Intelligent processes (modeling/simulation, automation, rapid prototyping).
- Emerging technologies (science based manufacturing, nanotechnology).
- Education (research, collaborative environments, manufacturing curriculum).

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Ceramic Nanofibers-based Metal Matrix Composites

Benefits

Electroforming is a unique technique that allows for orientation control of nanofibers during codeposition with metal. Therefore, using this unique technology, MMCs of higher strength and modulus can be achieved. Oriented fibers in the matrix impart higher strength and stiffness than randomly oriented fibers. This advanced process could be attractive for manufacturing of lightweight critical components for space structures and rocket engines.

Point of Contact

Raj Kaul/ED34
Phone: 256–544–1084
Email: Raj.K.Kaul@nasa.gov

Objective

The objective of this proposed research is to develop and optimize an MMC electroforming technique using ceramic nanofibers as reinforcement. The electroforming of Al_2O_3 or other nanofibers—reinforced nickel, nickel aluminide, and copper matrix composites—is a major focus of the MSFC advanced manufacturing technology in the development of MMCs.

Approach

This effort builds on work previously done at MSFC, the results of which are quite remarkable and promising for further investigation. Specifically, a nickel or copper metal matrix with Al_2O_3 nanofiber reinforcement will be investigated. These nanofibers will be Ni-coated using an in-house developed proprietary method. These coated fibers can be manipulated by the magnetic field during the electrodeposition process controlling the amount and the alignment of the entrapped fibers. A significant effort will be devoted to magnetic field engineering. The electroformed MMCs microstructure, mechanical, and physical properties will be characterized in-depth. Optimal processing parameters will be determined. The effort will concentrate on three areas: 1) the electroforming process, to investigate the role of various technological parameters of the process, such as current density, electrolyte temperature, flow control, and concentration of nanofibers; 2) magnetic field, to design suitable dynamic magnetic field structures that could yield uniform deposition rate of nanofibers in a particular orientation during electroforming process; and 3) characterization of samples, focusing on microstructure (Scanning electron microscope/X-ray defraction) and mechanical properties of the samples. Electroforming technology of lightweight MMC with oriented fibers and enhanced mechanical properties at ambient and elevated temperatures will be developed.

Deliverables

- An MMC electroforming technique using ceramic nanofibers for reinforcement.

Film Module for Automated Fabrication of Composites Having Barrier Films and Core Adhesives

Objective

The objectives of this effort are:

- To develop a prototype film supply and feed module that can be integrated with a current fiber placement system, located in the NCAM facility at MSFC.
- To use the film module in concert with the fiber placement machine to fabricate test panels.
- To gain an understanding of the subtleties in the processing of thin films into composite laminates by automated means. Results of these tests will be used, along with other indicators, in an attempt to quantify and assess this automated processing method.

Approach

The project will consist of three distinct phases:

Design and Fabrication

- Perform preliminary design conceptualization.
- Finalize design and produce machine drawings.
- Procure hardware and machine module hardware.

Checkout and Machine Integration

- Initiate and complete assembly of film module.
- Perform preliminary mechanical checkout system.
- Integrate module with existing fiber placement machine head.
- Perform integration checkout and troubleshooting.

Panel Fabrication, Testing and Reporting

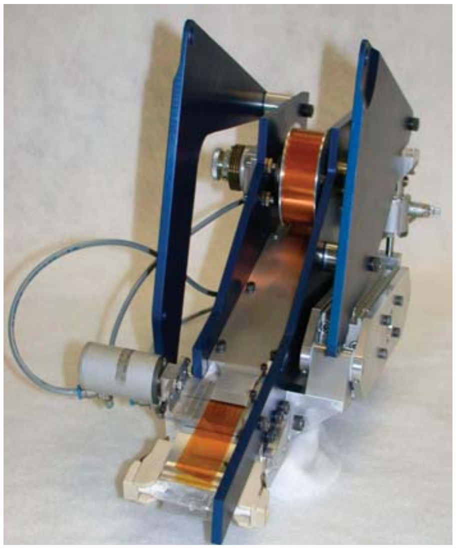
- Fabricate panels for testing.
- Machine test panels into specimens and perform tests.
- Document results.

Deliverables

- Integrated film processing module.
- Test panel fabrication and evaluation.

Benefits

Materials property testing is currently being performed to test the hydrogen permeability of selected polymeric and metallized thin films for use in cryogenic tank applications. Such thin films may be incorporated into a laminated composite material system as a barrier against cryogen permeation through a tank wall. If such material systems are to become feasible for use in cryogenic tanks for the next generation of space launch vehicles, new methods for tank fabrication must be developed. Out-of-autoclave processing of composite tanks has been deemed essential in the fabrication of future cryogenic tanks, and automated fiber placement is one method under current investigation for the fabrication of such tanks, and is the most probable method of manufacturing tanks having thin barrier films.



Point of Contact

Bruce Hulcher/ED34
Phone: 256–544–5124
Email: anthony.b.hulcher@nasa.gov

Rotational Vacuum-assisted Resin Transfer Molding for Non-autoclave Processing of Components

Benefits

Currently, most high-performance aerospace composites are autoclave processed. However, this process is not economically feasible for the production of very large components such as propellant tanks. The VARTM process, though used extensively to manufacture composite articles, has had limitations that have precluded its use in the processing of high-performance components. This effort will utilize a modification of this process that will result in a cost-effective ability to produce large composite structures out-of-autoclave. The innovation to this process will substantially improve fiber-dominated mechanical properties of composites currently obtained with this method.

Objective

The objective of this effort is to demonstrate through a modification of the Vacuum-assisted Resin Transfer Molding (VARTM) process, that higher performance composites may be fabricated by this cost-effective, out-of-autoclave method, that will have substantially improved fiber-dominated mechanical properties and improved resistance to microcracking at cryogenic temperatures. Additionally, matrix resin systems that have been shown to be resistant to microcracking at cryogenic temperatures and to be processable by VARTM will be incorporated into this work. Additionally, this innovation is scaleable to the manufacture of much larger composite components.

Approach

The project consists of three phases:

Planning and Procurement Processing Trials

- Perform trials using tow and baseline fabric preform materials.
- Perform trials using additional mass to assist preform compaction.
- Optimize fiber volume.

Optimization, Testing, and Evaluation

- Perform void content and fiber volume analyses to optimize process parameters for both baseline and other preform materials.
- Perform mechanical property tests to determine quality of optimized composite.
- Report final results.

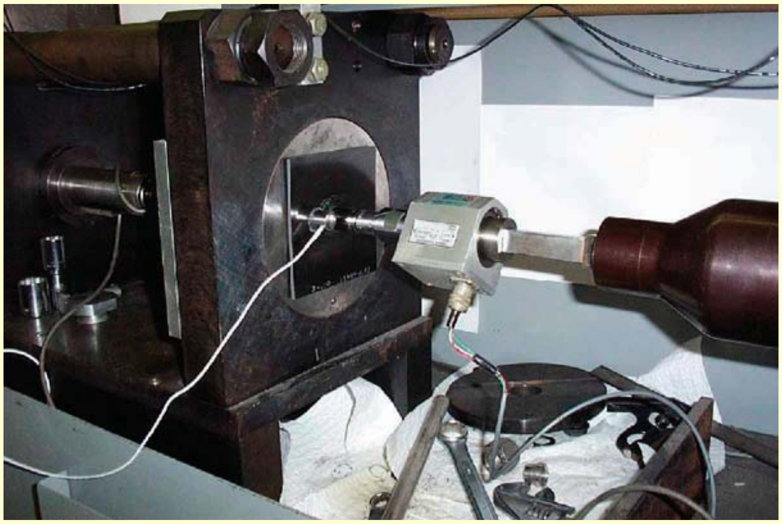
Deliverables

- A new composite processing method.
- Process optimization studies.
- Characterizationn of fabricated composites.
- 9- to 18-inch diameter cylindrical test articles.

Point of Contact

Bruce Hulcher/ED34
Phone: 256–544–5124
Email: anthony.b.hulcher@nasa.gov

Torque Limit for Fasteners in Composites



Objective

The objective of this effort is to perform sufficient empirical tests to develop a standard method of determining the torque applied to metallic mechanical fasteners when used to join composite materials.

Approach

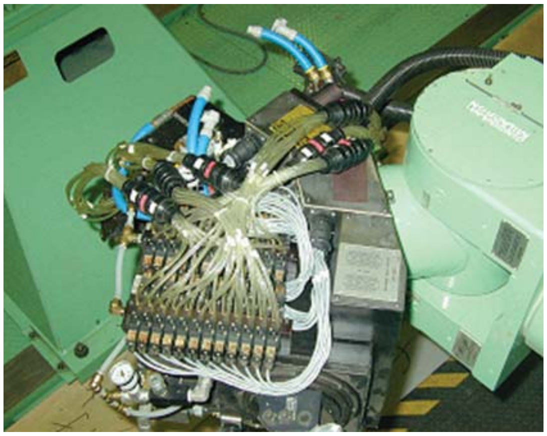
This task investigates the use of metallic mechanical fasteners for joining high-load composite structures, and it will provide empirical validation for using standard torqueing values when joining composite materials. The effort will be accomplished by initially determining the through-the-thickness modulus of elasticity and compressive strength of a composite material with a particular fiber but various matrices. Once the material properties are determined, an analytical model will be developed to predict the required torque. The model will be verified through torque-tension testing.

Deliverables

- This effort will provide an empirical basis for developing an initial torque standard for preloading continuous fiber reinforced polymer matrix composite materials joined with metallic mechanical fasteners.

Benefits

Currently, no standard torque value table exists for joining composite materials. The current method of specifying torque uses the MSFC–STD–486 standard, which is designed for joining isotropic materials rather than anisotropic materials. Aircraft companies join composite materials with mechanical fasteners or adhesively joined systems with a low load carrying capability. The results of this effort will allow MSFC to develop standard methods of torqueing mechanical fasteners for the joining of composite materials that designers can utilize without having to perform independent specific tests or utilizing vague or nonintuitive methods or standards. This work will establish MSFC as a lead for an industry standard.



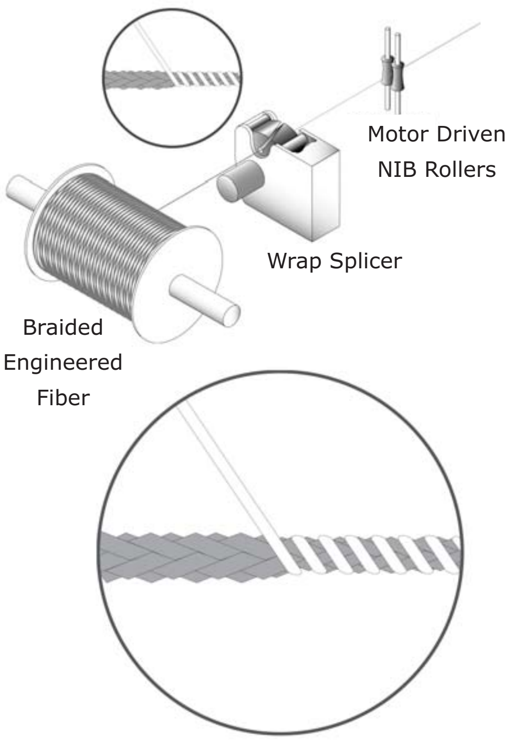
Point of Contact

Frank Thomas/ED23
Phone: 256–544–4936
Email: frank.p.thomas@nasa.gov

Deployable Structures Utilizing Spiral-wrapped Engineered Fibers

Benefits

There are no known current efforts dealing specifically with deployable structures that utilize spiral wrapping of engineered fibers. Current technology still relies on complex folding or coilable booms. The proposed concept shows promise in providing a compact, lightweight system for the on-orbit fabrication and deployment of structures of very long lengths. Several projects are proposing the use of large-scale, lightweight structures such as solar sails, antennas, and sunshades. The mechanisms required to deploy such objects will require state-of-the-art technology to meet these unprecedented size requirements.



Point of Contact

Mark Vaccaro/ED24
Phone: 256-544-7177
Email: mark.v.vaccaro@nasa.gov

Objective

The objective of this proposed effort is to develop the technology to produce high length-to-diameter ratio deployable booms, struts, and tethers. Specifically, it deals with the stiffening effect that occurs when braided engineered rope is spirally wrapped with additional fibers. At the completion of this effort, the structural properties of spiral-wrapped engineered fibers will have been characterized, and the ability to manufacture a rigidized fiber structure will have been demonstrated.

Approach

The research capitalizes on the investigators' work with Propulsive Small Expendable Deployer System (ProSEDs) tether systems, which indicated a surprising level of stiffness that could be imparted to a single braided fiber by spirally wrapping it with a single fiber under tension. This effort focuses on producing and characterizing various fiber configurations and their associated stiffness and load carrying capabilities. It utilizes the existing Tether Winding and Spark Testing facility to initially produce small-diameter samples. The facility will then be upgraded to produce larger samples. The resulting samples will be tested for load and stiffness characterization. A prototype design of a flight-like manufacturing mechanism will subsequently be developed.

Deliverables

- Small and large diameter test samples.
- Load and stiffness characterization test reports.
- Prototype design of flight-like mechanism.

Novel Approach to Fabricating Sample Containment Assemblies for Microgravity Materials Processing

Objective

The objective of this research is to develop and demonstrate Laser Engineering Net Shaping (LENS) processing parameters to fabricate hermetic Inconel and tungsten Sample Containment Assembly (SCA) cartridges. A new additive manufacturing laser sintering process available at MSFC will be employed to attempt the fabrication of these cartridges beginning with materials known to the process (steels) and progressively stepping up to refractory materials including tungsten and/or molybdenum. Goals of this effort will be to reduce the cost of cartridge fabrication by 40 percent and to reduce the time of fabrication from five days to three days.

Approach

Initial trials will be conducted on the LENS machine at MSFC using materials already known to the process, e.g. stainless steel 316, and then progressing through the materials—Inconel and tungsten—needed for the final flight hardware. SCA's will be laser-deposited with a standard geometry, and the length of the tubes required for porosity testing will be established during the experiment. Once a set of SS316 sample tubes have been successfully deposited, they will be tested to determine if the strength and porosity meet the requirements for SCAs. If the preliminary LENS parts are not hermetic, three alternative processes have been developed to resolve the issue.

Deliverables

- Coupons, tensile test specimens.
- Mechanical properties data for LENS-deposited Inconel and tungsten.
- Sample tubes in stainless steel, Inconel, and tungsten.
- Porosity data for all three materials.
- Optimized LENS operating parameters for these materials.

Benefits

For the past decade, sample cartridges for containment of toxic and reactive materials for microgravity materials processing have been difficult and expensive items to fabricate with various approaches attempted with very limited success. Current processing techniques are extremely expensive or nonhermetic or porous in nature, which is unacceptable for these hardware components. If the goals of this effort are achieved, the cost of cartridge fabrication will be reduced by 40 percent and the time of fabrication will be reduced from five days to three days. In addition, this effort will result in an expanded materials database for the Laser Deposition Research community, fulfill the projected needs for SCAs for *International Space Station* (*ISS*) experiments, and will provide useful information on refractory metal development to nuclear programs.

Point of Contact

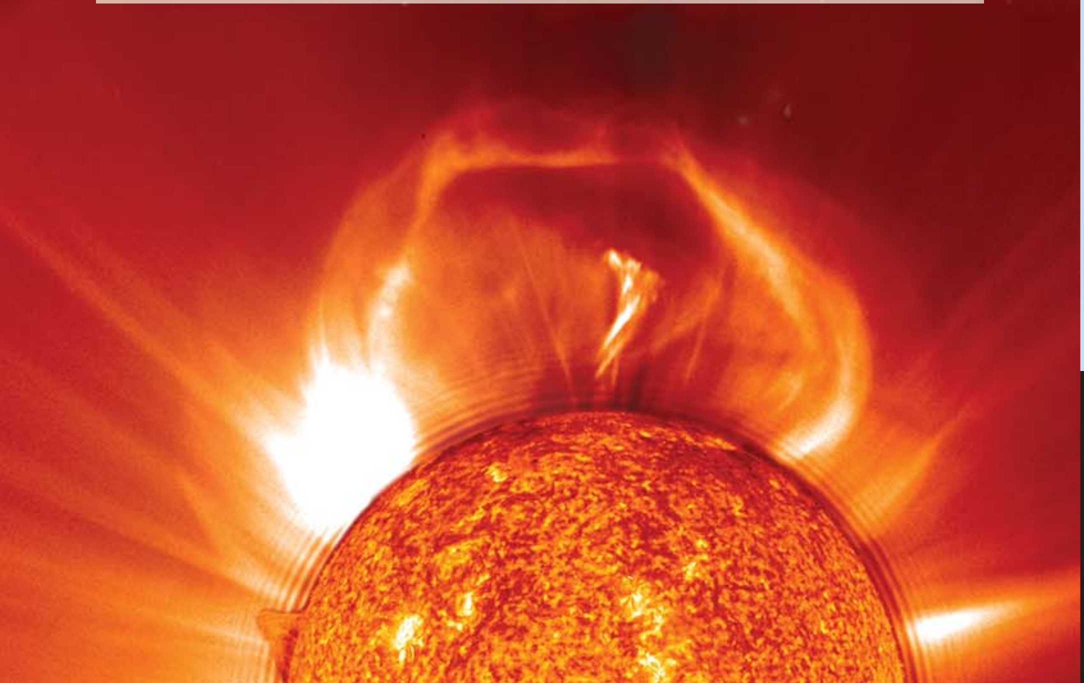
Glenn Williams/ED34
Phone: 256–544–1041
Email: glenn.a.williams@nasa.gov

Space Environmental Effects (SEE)

The Space Environmental Effects (SEE) Thrust Area is designed to provide an understanding of the hazards posed by space environments (natural and induced) to spacecraft and to develop techniques to mitigate their deleterious effects. The area will develop SEE technology necessary to meet future spacecraft requirements for material and system stability and long life in appropriate space environments.

This will be accomplished by identifying new and emerging technologies and future mission sets followed by development of the necessary SEE technology required for these missions. This area will build upon the already well-experienced, multidisciplinary expertise existing at MSFC in conjunction with established partnerships with other NASA Centers (LaRC, GSFC, and GRC).

Environment definition is one important part of evaluating the effects on spacecraft. New system analysis techniques and software will be developed for evaluation of SEE on space systems. The synergistic role between the space environment and contamination and ultimate degradation will be quantified. Advanced testing technologies and techniques to simulate space environments and evaluate their effects on materials and systems will be developed.



Engineering Directorate

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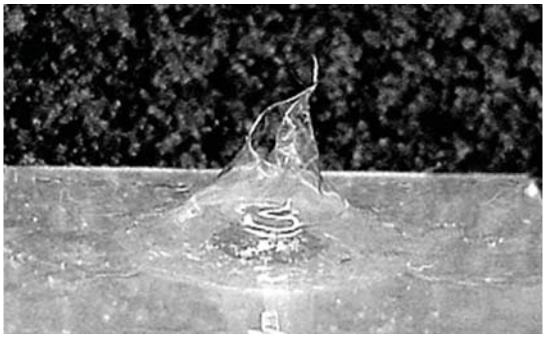
Space Environmental Effects on Ablative Laser Propulsion Using Propulsion Using Multilayer Material Systems

Benefits

- Beamed laser energy for spacecraft propulsion provides many benefits including lack of propellant mass and high specific impulse.
- Due to the difference in ablation processes, the use of multilayer material systems leads to coupling coefficients up to an order of magnitude higher than those for single-layer systems.
- Ablative laser propulsion can be used for a wide variety of applications from microthrusters to large-scale projects such as Earth-moon or orbit-to-orbit launches.
- A laser microthruster would provide propulsion for micro-, nano-, or picosatellites with continuous operation, large single-impulse dynamic range, good specific thrust, and excellent thrust-to-power ratio.



Objective

The primary objective of this effort is to characterize various multilayered materials applicable for use in laser-driven microthrusters through the measurement of their coupling efficiency both before and after exposure to SEE. The secondary objective is to determine and evaluate SEE on ablative laser propulsion efficiency of multilayer materials.

Approach

Laser ablative propulsion is an area of rapidly growing interest, especially in the area of micropropulsion and the development of microthrusters. Interest in this subject has been expressed by NASA, Defense Advanced Research Projects Agency (DARPA), and the Air Force. Although limited research in ablative laser propulsion is ongoing across the country, the optimization of the material systems, specifically in the area of SEE, has not been examined. This effort will characterize four multilayer material systems through determination of their coupling coefficients, measurement of the environmental degradation of polymeric layer materials due to SEE, and evaluation of the effect of this degradation on propulsion efficiency.

Deliverables

- Characterization of four multilayer material systems through determination of their coupling coefficients.
- Measurement of the environmental degradation of the polymeric layer materials due to SEE.
- Determination and evaluation of the effect of this degradation on propulsion efficiency.

Point of Contact

Mary Nehls/ED31
Phone: 256–544–7647
Email: mary.nehls@nasa.gov

Investigation to Compare Ground-simulated Space Environmental Effects on Material with Existing Geosynchronous Flight Data

Objective

The objective of this research is to perform ground-based SEE laboratory exposures and compare the results to actual flight data, in particular that from Geosynchronous Earth Orbit (GEO), to quantitatively validate the draft International Standard for SEE materials testing.

Approach

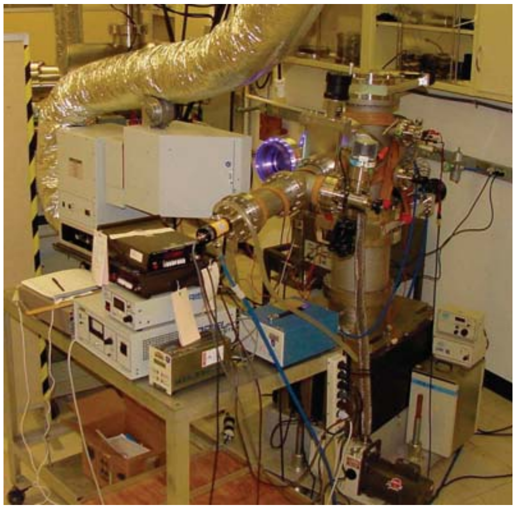
The environment at geosynchronous orbit will be determined and a dose-depth profile will be generated for materials such as the white thermal control coating Z–93 and silver teflon (Ag/FEP). The material will be characterized both pre- and postexposure to compare its thermal optical properties with the GEO flight data. This effort will utilize MSFC's unique facility for performing simultaneous exposure of space environmental components to test materials. While limited exposure facilities exist elsewhere, MSFC has the capability to expose material to a larger range of particle energies. By comparing the ground-based exposures to the GEO flight data, error analysis can be performed and constants can be identified to normalize the ground-based exposure data to actual flight data.

Deliverables

- Optimum ground-based test processes.
- Testing documentation providing spacecraft designers a higher confidence factor when selecting materials.

Benefits

Currently, limited ground-based testing exists that correlates to actual flight space exposures, particularly at GEO. The ground-based SEE testing of materials to be used in space is an important prerequisite for the construction of spacecraft since the SEE are a primary cause of material degradation, and ground-based testing is a primary method to ensure that the equipment constructed from the material will continue to function within necessary parameters during its planned lifetime. The result of this effort will ensure that spacecraft designers will have a higher safety assurance for materials to be used in spacecraft design. This work will also enhance and optimize laboratory processes for performing ground-based SEE exposure of materials.



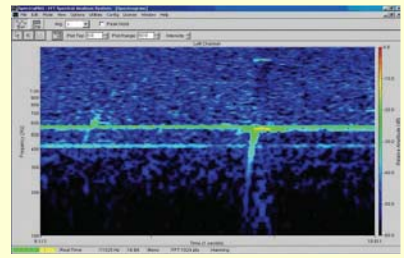
Point of Contact

David Hoppe/ED31
Phone: 256–544–8836
Email: david.t.hoppe@nasa.gov

Using Neural Networks/Genetic Algorithms to Identify Radar Meteor Signatures

Benefits

This effort allows adequate time to develop an improved method for identifying and counting meteor signals for use in a meteor stream model and forecast. These models and forecasts aid spacecraft developers and operators in tailoring their designs and procedures to specifically handle effects due to the meteoroid environment. Also, such innovative and technologically advanced algorithms and tools are important in providing advanced computing (artificial intelligence/neural networks/genetic algorithms) in the pursuit of science and technology discoveries. This work ultimately supports the meteor storm forecasting that the Engineering Systems Department provides to MSFC, GSFC, JSC, JPL, U.S. Air Force, and several commercial satellite operators. The results of the neural network/genetic algorithm in meteor counting will aid in the development of improved meteor stream models. The automation of this new meteor identification and counting process will hopefully eliminate false reads on meteors and improve our counting system. With the development of a better counting and identification system, the meteor stream model is improved and therefore the forecasts of meteor showers and storms are also improved.



Objective

The objective of this effort is to train a neural network and/or genetic algorithm to identify radar meteor signals from local forward scatter radar in order to aid in the development of improved meteor stream models.

Approach

Currently, analysis of this data involves separating meteor signals from the noise caused by lightning, tropospheric propagation of television carriers, large meteor echoes, etc. The forward scatter radar is tuned to several large TV station carrier signals throughout the southeast U.S. As the meteors enter the atmosphere, their ionization trail reflects a TV carrier and can be heard and picked up by the radar. The meteor signature appears as a "ping" in the radar receiver audio, sometimes accompanied by a shift in frequency over time due to doppler effect of deceleration of the meteor head. The genetic algorithm and/or neural network will be trained using thousands of data sets from our library of audio spectrograph files of radar meteor signals. Once trained, the network/algorithm will be set up to automatically detect and count meteors from the forward scatter radar. Neural networks should be especially effective at meteor recognition, since a human can do the job with a little training. This effort will research different neural networks and genetic algorithms for suitable candidates and apply them to the data collected using a forward scatter radar.

Deliverables

- Automated meteor identification process for analyzing data collected with radar detection systems and to achieve real-time capability.

Point of Contact

Heather Lewis/ED44
Phone: 256–544–0686
Email: heather.m.lewis@nasa.gov

Charged-particle Environment Assessment Tool for Earth-Sun L1 and L2 Points

Objective

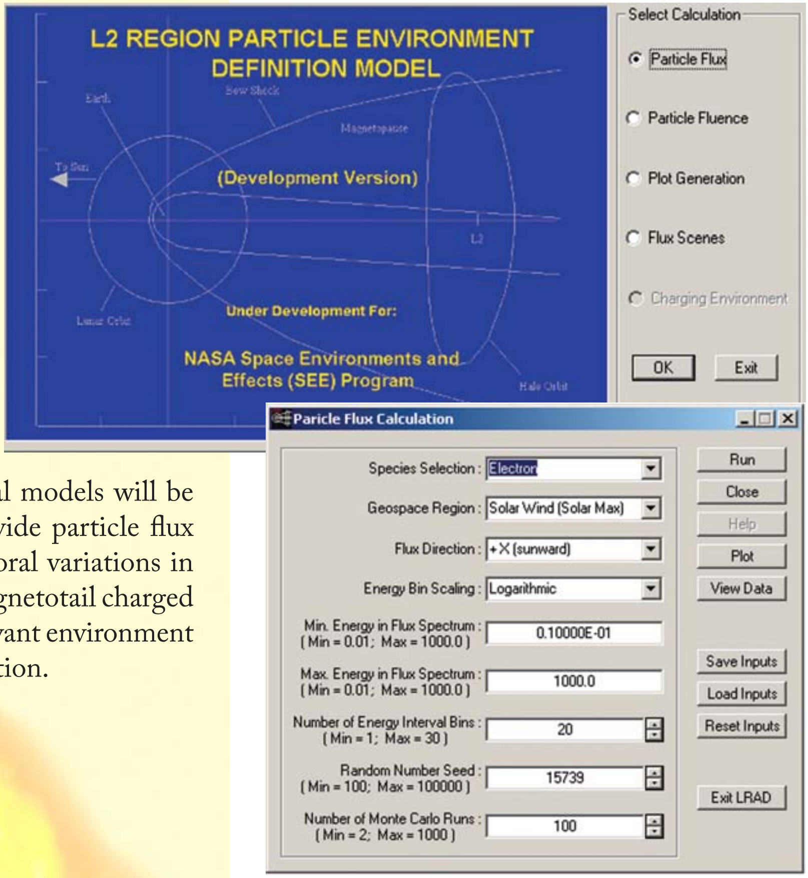
This effort provides a graphical user interface (GUI) for the L2 charged particle environment (L2–CPE) model already under development for the NASA Space Environments and Effects Program. The L2–CPE model updates the prototype L2 environment model—originally developed to provide plasma environments input to the Next Generation Space Telescope program—to a comprehensive, high-fidelity engineering analysis tool for predicting distant magnetotail and solar wind electron, proton, and helium environments to be encountered by spacecraft in the vicinity of the L2 point and solar wind environments in the sunward direction at the L1 point. The user of this tool will be able to calculate the flux and fluence values of the charged particle environment and display the results via a GUI.

Benefits

No engineering-level environments tool is currently available to provide predictions of the lower-energy charged-particle environment (few 10s eV through 1 MeV) and its variations in the plasma regimes (solar wind, magnetosheath, and magnetotail) sampled by spacecraft in orbit about the L2 point. This model will provide the environments needed for the predictions of spacecraft charging and materials degradation.

Approach

This effort involves both improvements in existing deep space environment models and the creation of a user-friendly graphical tool to portray the resulting data. The effort will increase the prototype L2 environment model's fidelity by creating databases of the plasma moment information recently obtained from spacecraft operating in the solar wind and deep geotail regions: Advanced Composition Explorer (ACE), Interplanetary Monitoring Platform-8 (IMP 8), Solar and Heliospheric Observatory (SOHO), Wind, and Geotail. Updates to the phenomenological models will be made so that the solar wind and geotail regions provide particle flux predictions that correctly take into account the temporal variations in magnitude and direction. A GUI incorporating the magnetotail charged particle model will allow the user to easily access all relevant environment information—flux, fluence, and dynamic scene generation.



Deliverables

- This effort will deliver a complete tool including GUI and documentation.

Point of Contact

Rob Suggs/ED44
Phone: 256–544–2704
Email: rob.suggs@nasa.gov

Ultraviolet Radiation and Atomic Oxygen Interaction With Molecular Contamination on External Spacecraft Surfaces

Benefits

A quantitative understanding of the synergism between UV, AO, and molecular contamination will be developed. The knowledge gained will support operational decisions and design efforts for long-lived spacecraft operating in Low Earth Orbit, such as the *ISS*, the Hubble Space telescope, and the Chandra X-ray Observatory. This information would also facilitate the selection of materials by spacecraft designers. It would also contribute the quantitative information needed for the enhancement of models that are used for the prediction of optical and thermal control surface degradation in low earth orbit.

Point of Contact

Keith Albyn/ED31
Phone: 256–544–8011
Email: keith.c.albyn@nasa.gov

Objective

The objective of this effort is to quantify the synergistic interaction of vacuum ultraviolet radiation (VUV) and atomic oxygen (AO) with deposits of molecular contaminants on a simulated optical surface and provide a fully operational system for photo-deposition studies. Capitalizing on the use of existing facilities at MSFC, this effort will provide quantitative measurements of UV and AO interaction with molecular contaminants from common spacecraft materials. In addition, this effort will provide surface dwell times and ionization cross-sections for molecular contaminants representing the major classes of materials (hydrocarbons, silicones, and ceramic surface coatings) used in the construction of spacecraft.

Approach

Spacecraft candidate materials will be subjected to VUV and AO separately while the rate of molecular contamination deposited on a quartz crystal microbalance (QCM) is measured, establishing a baseline for the interaction of the individual parameters with the molecular deposition process. Following this, a quantitative study of the synergy between AO and UV will be made by monitoring the increased rate of molecular deposition or removal of previously deposited molecular contaminants from the QCM surface.

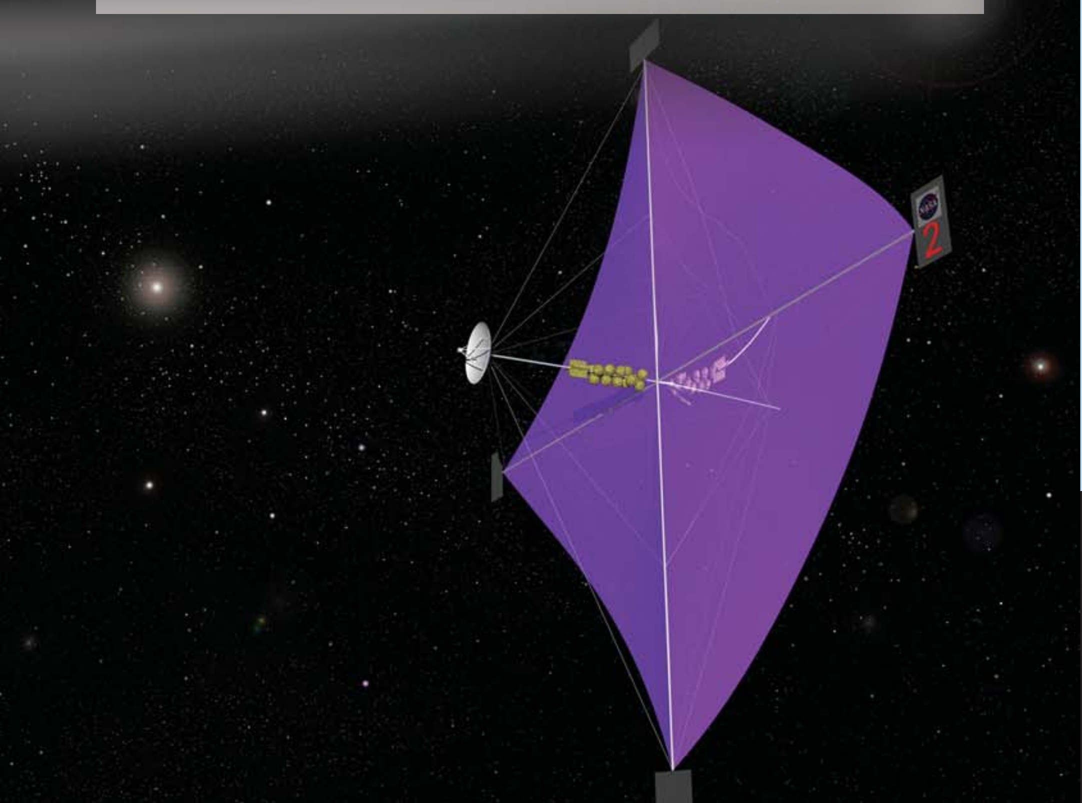
Deliverables

- Quantitative measurements of UV and AO interaction with molecular contaminants from common spacecraft materials.
- Surface dwell times and ionization cross-sections for molecular contaminants representing major classes of materials—e.g., hydrocarbons, silicones, and ceramic surface coatings.

Advanced Structures and Materials

The Advanced Structures and Materials Thrust Area is chartered to generate advanced structures and materials technology management plans for the Engineering Directorate by fostering stronger integration between the structures and materials disciplines and emphasizing strategic planning and partnering. It will work closely with both the Advanced Manufacturing and Advanced Cryotanks Thrust Areas.

- Smart structures: Design and fabrication of composite smart panels, embedded fiber optics in manufacturing process.
- Structural design techniques: Development of advanced material joint design methodology, internal damage assessment tool for composites.
- Advanced materials development and characterization: Design and fabrication of test specimens using advanced composites, new-age metallic combinations, and novel approaches.
- Integrated design: Design and fabrication of structures incorporating open-section structural members and embedded sensors.



ENGINEERING
DIRECTORATE

Marshall Space Flight Center
Huntsville, AL

http://etdo.msfc.nasa.gov

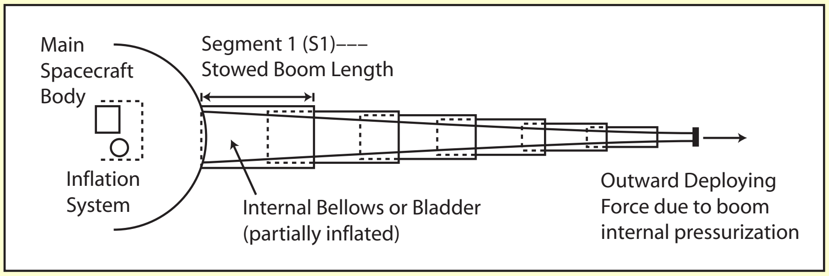
Advanced Thin-film Composite Structures Including Smart Components

Benefits

While several concepts are being developed by industry for lightweight deployable structures, most of them are relatively complex, and some have significant outgassing during cure, which can contaminate optical surfaces. The proposed inflatable telescoping boom is a new concept that (a) eliminates the requirement for complex material rigidization schemes, (b) minimizes outgassing, and (c) is simple conceptually and operationally. Telescoping booms are not a new idea, but the idea of an inflation-deployed very lightweight boom is new. The thin-film honeycomb panel is an extension of the foam-rigidized tubes fabricated in a previous CDDF project. These structures potentially enhance or enable future missions such as solar sails and solar thermal propulsion, and could improve solar array design.

Point of Contact

Mike Tinker/ED21
Phone: 256–544–4973
Email: michael.l.tinker@nasa.gov



Objective

The objective of this effort is to develop two new and innovative thin-film composite structures:

- an inflatable telescoping composite boom.
- a thin-film honeycomb panel with a foam core.

Design, construction, and deployment techniques will be investigated for these advanced and innovative thin-film composite structures. Prototype articles will be fabricated to demonstrate feasibility of the concepts, to conduct structural characterization tests, and to develop models for comparison to test results. In addition, the use of smart piezoelectric sensor/actuators for dynamic testing and vibration control of thin-film structures will be evaluated.

Approach

- Inflatable telescoping boom.
- Design and materials selection.
- Fabrication and deployment.
- Thin-film honeycomb panels.
- Modal testing.
- Structural dynamic finite element modeling.
- Piezoelectric devices.
- Investigate use as a means of dynamic testing and vibration control.

Deliverables

- Prototype articles.
- Inflatable boom.
- Thin-film honeycomb panel.
- Analytical Flight Experiment models of hardware.

Structural Testing of a Silicon Carbide Fiber/Silicone Carbide Matrix Membrane

Objective

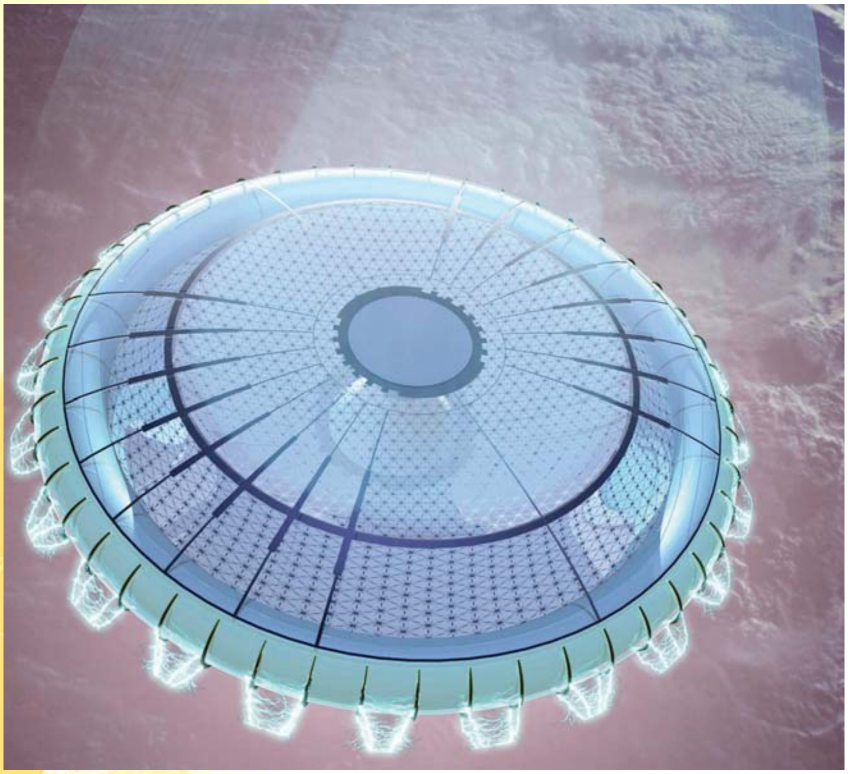
The primary objective of the proposed task is to characterize the structural stiffness and strength properties of silicon carbide fiber/silicon carbide matrix (SiC/SiC) ceramic composite membranes. A secondary objective is to develop manufacturing, handling, and testing experience with ceramic membrane structures. This research will have direct application to the current Microwave Lightcraft (MWLC) effort, since the current design uses silicon carbide as the principal structural material. The thickness of the proposed test specimens is exactly the same as the proposed thickness of the MWLC hull face sheets. This material could also have applications in other high performance aerospace structures. Silicon carbide composites have the potential to increase specific stiffness by a factor of five and to increase specific strength by a factor of four over steel. However, little experience exists with using SiC/SiC composites as a structural element, and there has been no research conducted with SiC/SiC structural membranes.

Benefits

SiC has been evaluated by laboratory research for electronic and thermal applications. Based on this research, the elastic modulus of the composite membrane structure is anticipated to be roughly 400 GPa, and strength to be roughly 2.0 GPa. However, serious evaluation of SiC/SiC materials for structural applications such as the MWLC requires research aimed specifically at obtaining structural properties.

Approach

Single ply-test specimens of SiC/SiC composite material will be fabricated in the form of thin circular disks for testing in the MSFC Hydrogen Test Facility. The specimens will be sealed and then pressurized on one side to create maximum stress at the center of the specimen. A laser device will be used to measure center deflection of the membrane specimen in order to calculate the structural stiffness of the specimens. Pressure data and/or burst tests will be performed to calculate specimen strength.



Deliverables

- This research will provide hard data on the structural capabilities of SiC composite membranes.

Point of Contact

Eric Poole/ED22
Phone: 256–544–2723
Email: eric.l.poole@nasa.gov

Optimization of a Time-domain Parameter Estimation Procedure Using a Genetic Algorithm

Benefits

The proposed methodology provides an additional parameter estimation tool beyond those typically used in the industry. Time domain modal parameter estimation has the added advantage that it may be applied to nonlinear data. Current frequency domain techniques are based on the assumption that the data is linear. The application of a genetic algorithm to optimize the modal parameters provides an evolutionary approach to analysis of dynamic time histories. A new, optimized time domain analysis method could benefit multiple programs. In particular, all shuttle payloads and many components, as well as new hardware currently in development, require modal testing. A more accurate experimental description of the dynamic behavior of the structures will lower the uncertainty in the modeling and analysis of these structures. The method may also be extended into the analysis of operating data—response data taken during the actual operation of equipment. This would particularly be beneficial in the area of engine testing.

Objective

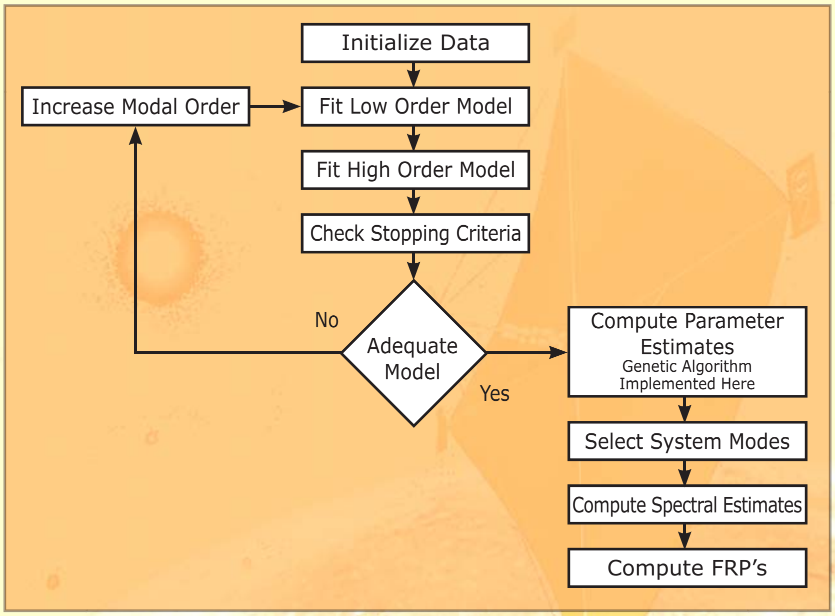
The objective of this effort is to implement a genetic algorithm to optimize the estimation of modal parameters using a time domain technique.

Approach

This effort continues earlier research to implement evolutionary concepts for structural dynamics system identification of space flight hardware and consists of four primary tasks: 1) to develop proficiency with current algorithms and software utilizing both analytical and experimental data; 2) to conduct genetic algorithm trade studies to ascertain the optimal genetic algorithm for determining the modal parameters; 3) to implement selected genetic algorithms by integrating the genetic algorithm with the existing time domain estimation code; and 4) to document the findings of the project and make recommendations for further study.

Deliverables

- A software tool for analysis of dynamic data in the time domain.
- A genetic algorithm will be implemented to optimize the parameter estimation process.



Point of Contact

Kathy Kappus/ED27
Phone: 256–544–1125
Email: kathy.kappus@nasa.gov

Adaptive Structures Applications in Microgravity Vibration Control and Isolation

Objective

The purpose of this effort is to determine whether adaptive structures can effectively be used within space station racks, at either shelf or integrated rack level, to control internal vibratory disturbances by producing a test-validated model of adaptive materials' vibration attenuation properties/behavior. It will also address the question of whether or not these systems can be effectively utilized in an add-on fashion attached to prefabricated racks or rack components, or are only suited for built-in applications. This collaborative effort will evaluate and test whether existing technology developed at LaRC will meet the needs of the *ISS* microgravity experiments.

Approach

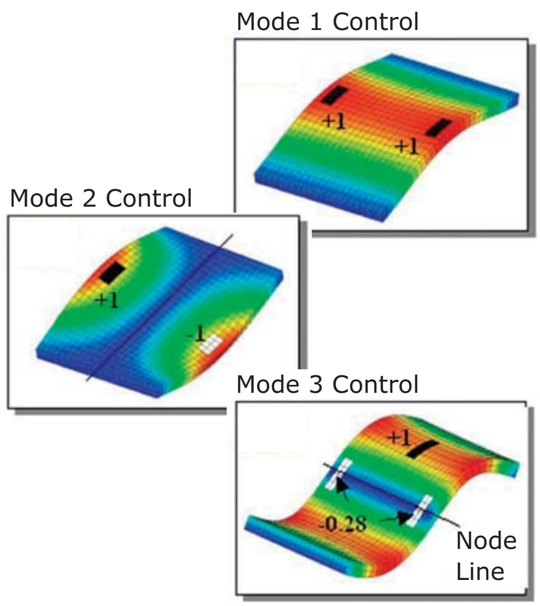
This effort will utilize adaptive structures—those incorporating actuators—to implement both passive and active vibration control techniques that reduce shelf-level vibrations within *ISS* experiment racks. In combining these two approaches through the use of adaptive structures, it is often possible to provide optimum vibration control and isolation in a structure. One technique is to control vibrations before they enter the shelf, such as when using a purely passive isolator. By controlling vibrations before they enter using improved semiactive isolators, the resulting shelf vibration environment can be improved. The second technique addresses the control of vibrations via active methods, in which a full range of vibration control can be achieved. In particular, this effort will develop a methodology to determine how effective piezoelectric patches can influence and attenuate noise and vibration in *ISS* racks and experiments.

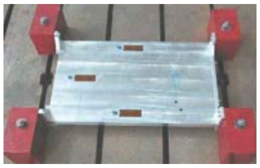
Deliverables

- New concept for component isolation on-orbit developed, fabricated, and tested.
- Microstiffness offload system developed for zero-g suspension of components during test.

Benefits

The microgravity environment aboard the *ISS* is one of the premier features of the orbiting platform. Many experiments planned for the *ISS* have the requirement of a calm, vibration-free environment. Due to a variety of disturbances on the experiment shelves, from both steady-state and transient sources, the acceleration levels on a particular shelf may exceed the requirements of some of these experiments. This effort will address the issue of methods needed to prevent these vibrations, thus improving the microgravity environment. The ability to predict vibratory response and perform dynamic testing will also help to effectively integrate the adaptive structures research into flight hardware.





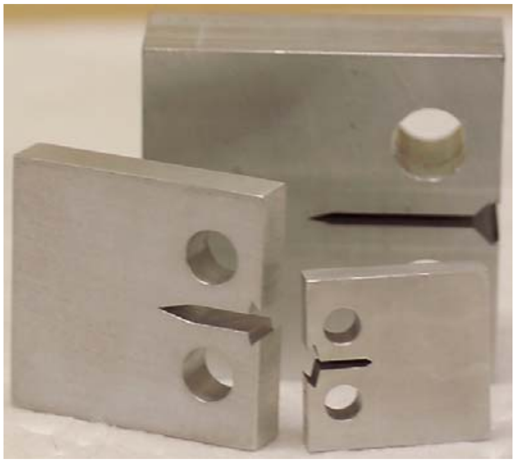
Point of Contact

Christy Gattis/ED21
Phone: 256–544–4114
Email: christy.b.gattis@nasa.gov

Cryogenic Fracture Toughness Evaluation of Cast Al-Be Alloys for Structural Applications

Benefits

Al-Be alloys provide lightweight, high-stiffness, good damping, and low coefficient of thermal expansion (COE) applications that are ideal for use in satellite components, avionics packaging, and aircraft/missile systems. The relatively new investment cast alloys have not had their mechanical or fracture properties characterized at cryogenic (–423 °F) temperatures, and mechanical and fracture properties at liquid hydrogen temperatures are required by designers to support stress analyses for programs. The availability of fracture properties at liquid hydrogen temperatures for this alloy will engender wider use of the investment cast alloy in satellite applications (low-temperature space applications).



Objective

The objective of this research is to determine the cryogenic (–423 °F) fracture properties (K1c, J1c, da/dN) for a promising new aluminum-beryllium (Al-Be) alloy manufactured using the investment casting process. MSFC has the unique capability to perform mechanical and fracture testing at liquid hydrogen temperatures to determine the mechanical properties at these temperature and environmental conditions. Development of cryogenic (–423 °F) fracture properties for the investment cast Beralcast–363 alloy will also enhance the MSFC Materials ands Processes Technical Information System (MAPTIS) database. Parameters for NASGRO (flaw growth software) will be determined and added to this software database.

Approach

Material in the form of investment cast plates will be procured, and test specimens for basic mechanical and fracture properties will be machined from them. Basic mechanical properties will first be obtained at room temperature to verify advertised material mechanical properties in preparation for cryogenic fracture testing. Fracture toughness testing at cryogenic temperatures will be obtained for the material.

Deliverables

- Cryogenic fracture properties will be obtained for cast Al-Be Alloys and input into MAPTIS.

Point of Contact

Wayne Gamwell/ED33
Phone: 256–544–2592
Email: wayne.r.gamwell@nasa.gov

Characterization and Selection of Carbon Fiber for Use in Ceramic Matrix Composites

Objective

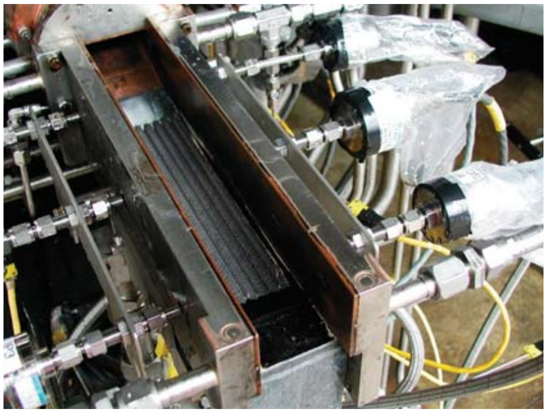
The objective of this research is to evaluate the effect of different heat treatment cycles on the physical, mechanical, and chemical properties of carbon fibers and to compile this data into a usable database. This database will enable selection of the best fiber, for a specific CMC, in order to maximize the lifetime and performance of the end component. This effort will examine how a wide variety of carbon fibers selected from different vendors respond to a range of heat treatment conditions and parameters. This will establish a database of properties including strength, strain, surface roughness, interlayer spacing, axial thermal expansion, and thermal conductivity.

Approach

This effort is comprised of three major tasks: 1) selecting about 30 different carbon fibers from different vendors to envelope different fiber precursors, processes, and types of carbon fiber, (2) establishing heat treatment conditions and parameters (ranging from 1,700 ˚C to 2,000 ˚C and at dwell times of 10 minutes to a few hours), (3) characterizing and comparing various physical and chemical properties (strength, strain, surface roughness, interlayer spacing, geometric surface area (with BET), chemically active surface area , carbon assay, axial thermal expansion, and thermal conductivity) before and after heat treatment. The heat treated carbon fiber(s) will be fabricated into composites to verify the transfer of the fiber properties into the composite properties and to compare to base line carbon fiber reinforced ceramics composites.

Deliverables

- A database of carbon fiber properties based on heat treatment history.
- Trend analyses correlating the effects of the heat treating processes with the resulting changes in fiber properties.
- Comparison of the physical and chemical properties of virgin versus heat-treated fibers.
- CMC specimens fabricated using fiber heat treatment processes determined through this effort.



Benefits

CMCs fabricated out of carbon fibers in a silicon carbide matrix offer improvements in durability over a large temperature range with a corresponding reduction in weight for propulsion components. These components include heat exchangers/cooled panels, leading edges, blisks, combustors, and nozzles. There is little or no information, however, on how heat treating affects the carbon fibers NASA is interested in pursuing for use in space propulsion applications. The results of this effort will expand current knowledge in the use of carbon fiber composites and will provide environmental durability of carbon fiber reinforced CMCs for use in 2nd and 3rd generation propulsion and airframe components.

Point of Contact

Diep Trinh/ED34
Phone: 256–544–6797
Email: diep.v.trinh@@nasa.gov

Characterization of Carbon Nanotube Reinforced Nickel

Benefits

Nanotechnology is comprised of designing, fabricating, and the application of nanometer-scale systems. Carbon nanotubes are cylindrical molecules composed of carbon atoms in a regular hexagonal arrangement. If nanotubes can be uniformly dispersed in a supporting matrix to form structural materials, the resulting structures could be significantly lighter and stronger than current aerospace materials. This effort will yield a high specific strength material and a manufacturing process, potentially suitable for applications such as space-based optics and cryogenic tanks where weight reduction is a premium.

Objective

The objective of this effort is to develop a codeposition process producing a carbon-nanotube/nickel composite material with high specific strength. The results will develop a process for producing a high-strength composite with excellent strength-to-weight ratio, produce a high-strength metallic material which maintains or improves its thermal and electrical conductivities, and produce a material potentially suitable for applications such as space-based optics and cryogenic tanks. While there are several processes available to manufacture MMCs, most require high temperature and/or exposure to reactive gases—conditions that could destroy the unique nanotube structure and properties. This effort utilizes near-ambient conditions. The aim of this project is to optimize the codeposition process and determine the resulting material's properties. This effort varies a number of parameters involved in the process of electroplating nickel on a stainless steel substrate in order to optimize the nanotubes in the structure.

Approach

A carbon nanotube slurry will be added for codeposition to an electroplating process of plating nickel on stainless steel. It is known that several electrodeposition parameters can be varied to affect the composition and morphology of the resulting composite, including plating bath composition, bath operating temperature, plating current density, and mass transport—all of which contribute to the amount of codeposited carbon. These parameters will be varied to maximize the volume fraction of carbon nanotubes in the deposit. The resulting material will be analyzed and tested before a second level of optimization is pursued—i.e., the addition of surfactants. The testing of mechanical properties of the optimized material will be made, and large specimen plates will be electroformed and tensile specimens will be fabricated from the optimized material and tested.

Deliverables

- Process for producing a high-strength composite material.
- Material potentially suitable for space-based optics and cryogenic tanks.

Point of Contact

Hansel Gill/ED33
Phone: 256–544–9027
Email: hansel.d.gill@nasa.gov

Evolutionary Structure Analysis and Test

Objective

The objective of this effort is to investigate design of unconventional lightweight structures with improved vibrostructural properties that alleviate or eliminate active control system requirements. In addition, the effort seeks to apply evolutionary designs methods, especially microgenetic algorithms, to such structures, develop analytical methods for characterizing their vibration modes, and confirm the accuracy of such analytical projections by modal testing of sample structures. In particular, this effort will develop a software tool for design optimization and structural analysis of lightweight tensegrity structures with improved vibrostructural characteristics.

Approach

A Tensegrity Analysis Package (TAP) will be developed consisting of various tools that will help visualize, determine stability, and analyze for modes of vibration. A microgenetic algorithm will be developed and will interact with these tools to evolve a frequency-enhanced tensegrity structure. To investigate the effectiveness and accuracy of the TAP and microgenetic algorithm, baseline and frequency-enhanced cylindrical tensegrity structures will be designed and built. A modal test will then be conducted on both structures to verify the analytical prediction.

Deliverables

- MATLAB TAP.
- Microgenetic Algorithm Package for structural optimization.
- Baseline and optimized tensegrity structures.

Benefits

Potential applications for this effort include vehicle internal support structures, spacecraft structural members, antennas, instrument booms, and solar array, telescope, and solar thermal propulsion system optics support structures. For example, future Gossamer spacecraft and vehicles, including telescopes and solar thermal propulsion vehicles, will ultimately tend toward tensegrity structures to optimize payload weight, strength, stiffness, and stowed volume. Such structures may be a primary element of a spacecraft, or provide support to antennas and reflectors. Current efforts are focused on the conceptually simple tensegrity structures. Future efforts will attempt to generalize these genetic algorithm techniques to more conventional structures. Starting with a conventional baseline design, the effort will make use of the "irregularization" capabilities of genetic algorithms to produce lighter-weight structures with improved structural characteristics.

Point of Contact

Russel Parks/ED27
Phone: 256–961–1124
Email: russel.a.parks@nasa.gov

NASA–23: High-strength, Tough, Cheap, and Hydrogen Embrittlement-resistant Superalloy

Benefits

Engineers now have a new material with both high strength and oxidation and hydrogen resistance to choose from. Its application is unlimited. The mechanical and other property database will be available to the public through the latest versions of the Aerospace Materials Handbook. Typical thermomechanically processed properties are as seen below.

Test Medium	Air	5 ksi H_2 (HEE)
YS in ksi	154.3	154.4
UTS in ksi 20.7	208	209
%E1	20.7	19.8
%RA	42.8	35.3

Objective

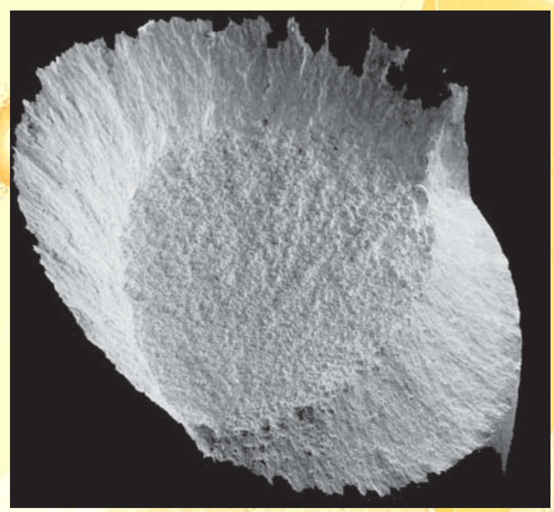
Most superalloys available today are designed for room- and high-temperature strength, toughness, oxidation, and corrosion resistance. However, they all perform poorly by losing their ductility (toughness) after exposure to a hydrogen environment. This is largely because the alloying elements that impart oxidation and corrosion resistance reduce hydrogen resistance. Since the alloy manufacturers over the years failed to address NASA's unique need for high-strength alloys that handle hydrogen, an alloy designated NASA–23 has been developed that has adequate resistance to hydrogen as well as has moderate oxidation and excellent corrosion resistance.

Approach

The alloy has been formulated by judicious selection of elements to combat hydrogen, as well as economical availability. In-depth understanding of hydrogen resistance mechanisms active in alloys such as IN–903 and IN–907 led to several experimental alloy chemistries. Finally, NASA–23 is a tweaked form of the best of these chemistries.

Deliverables

- **Future Efforts:** To utilize the full potential of this alloy and to determine its processing window, the alloy is currently being tested and characterized in powder metallurgy form.



Point of Contact

Binayak Panda/ED33
Phone: 256–544–6349
Email: binayak.panda@nasa.gov

Secondary Ion Mass Spectroscopy (SIMS): A New Analytical Tool for Failure Analysis

Objective

Failure analysis involves identification of minute particles, elements, or environmental effects that cause a component to fail. In most cases it is imperative that the chemistry of the particle, the element, or the environment effect is known. Unfortunately, all the electron microscopes and tools used in failure analysis cannot analyze light elements such as Be, Li, and H. The objective of this effort is to identify such an analytical tool and to develop the means to utilize the tool for failure analysis.

Approach

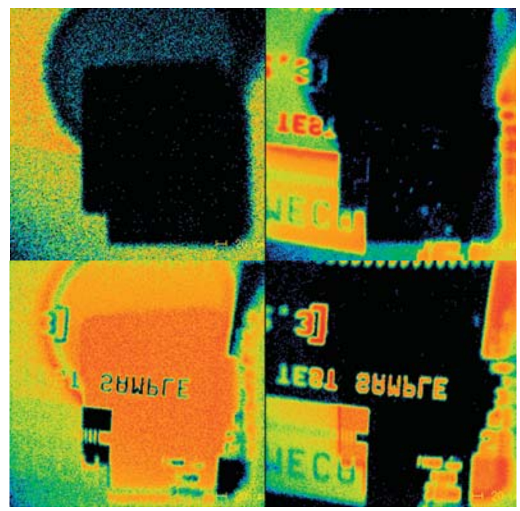
Secondary Ion Mass Spectroscopy (SIMS) has been used in solid-state materials technology to determine very light elements, parts-per-million level impurities, and isotopes of elements. The MSFC approach has been to procure a SIMS and to utilize it to analyze solids for contents of Li, H, and Be without destroying the sample. A state-of-the-art SIMS (Cameca IMS-6f) has been procured by MSFC and will be utilized for this effort. Since such instruments are used to analyze impurity elements in high-purity layered materials, experimental techniques need to be developed to analyze engineering alloys/materials with many alloying elements.

Deliverables

- **Future Efforts:** Develop methodologies such that the benefits are reaped with minimum efforts.

Benefits

The use of SIMS will successfully analyze Li segregations in Al-Li alloys; hydrogen in components exposed to or failed by rocket fuel; and trace element analysis (e.g., sulfur in electrodeposited Ni). The instrument will also be utilized to determine isotope ratios for many elements, identifying the origins of these materials.



Point of Contact

Binayak Panda/ED33
Phone: 256–544–6349
Email: binayak.panda@nasa.gov

Determination of Stiffness Modulii of Composites Using Modal Test

Benefits

Developing a capability to reliably perform structural analysis on composite materials is among one of the critical technologies necessary for the success of next generation launch vehicles. Because of the enormous variability in both the type of fibers and resins used and in the final lay-up chosen, though, the stiffness modulii, which are different for each axis, are not adequately documented. Traditional lamination theory for analytically determining the stiffness properties based upon the individual ply properties are useful for general estimates, but because of the complexity of many structural lay-ups, these estimates frequently have up to 25 percent error. Final analyses, therefore, require that the modulii be experimentally determined for each different case. Present static testing methods are fairly tractable for simple layups and individual ply testing, but more complex layups, such as the sandwich construction, may present more difficulty for static testing due to the complexity of fixturing, loading, and measuring such configurations. Since free-free modal testing can be performed with relative ease on virtually any structure with limited set-up time, no required fixturing, and with portable impact hammers, this method has the potential of being significantly easier than standard static loading methods.

Point of Contact

Andrew Brown/ED21
Phone: 256–544–1584
Email: Andy.Brown@nasa.gov

Objective

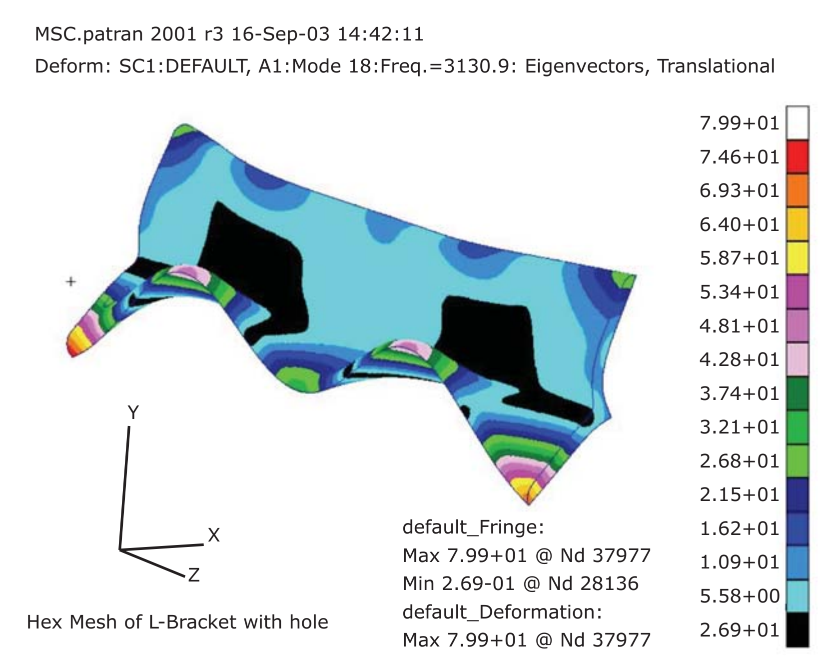
The objective of this effort is to evaluate whether dynamic modal testing can be used to determine the anisotropic stiffness modulii of aerospace composite structures. The application of this method would be a valuable supplement to existing static methods for in-situ structures as well as for lowering cost.

Approach

- Undertake detailed literature survey on existing methods for determining material properties based on modal testing, emphasizing parameter optimization and frequency response function analysis.
- Thorough investigation of existing methods for material property determination for composites.
- Testing of selected coupons using static and dynamic methods.

Deliverables

- A documented technique for using modal testing to determine anisotropic stiffness modulii of aerospace composite structures detailing issues with mass loading, appropriate excitation, and error analysis.



Hex Mesh of L-Bracket with hole

Evaluation, Development, and Testing of Metal Foams for Structural Use in Space Hardware

Objective

The objective of this effort is to evaluate existing metal foams for space applications by enhancing their mechanical properties through sandwiching and heat treatment.

Approach

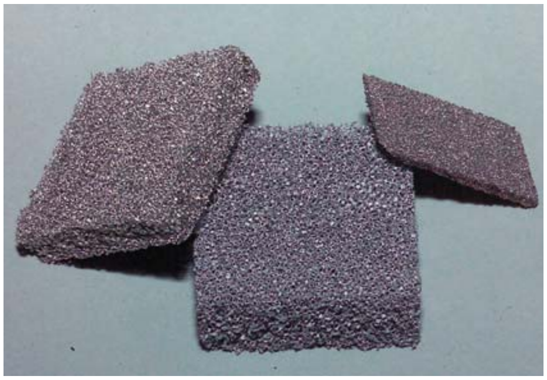
This effort will characterize in-depth selected alloy foams (steel, Al alloy, and superalloy) to study their feasibility for mechanical property enhancement and sandwiching, focusing on the microstructure, quality, and property reliability aspects. The selected materials will be surface/heat treated to enhance properties and subsequently brazed to form a composite material, since brazing techniques are used to join stronger/dissimilar alloy skins to the foam, making the composite more appropriate for structural applications. Once the sandwich is made, its mechanical properties will be tested with a bend test—an important test for plate materials. Following bend testing, original and failed samples will be cut out of the plates and will be characterized for microstructure and failure modes with the results that a viable foam material would be available for design considerations. Additionally, materials will also be manufactured in order to identify replacement components. A database of applicable materials will then be generated. It is expected that at the end of the effort there will be significant development in the mechanical properties of the existing foams. A new generation of composite materials will emerge whose applications will be invaluable to space missions.

Deliverables

- A materials database for metal foams with enhanced mechanical properties through sandwiching and heat treatments.

Benefits

Such metal foams are not only lighter in weight with the same stiffness as the parent solid metal, but also have high heat transfer and damping capabilities, which makes them candidate materials for aerospace structures. The weight savings provided by such structures would be invaluable to space missions by enabling heavier payload capabilities. Also, the inherent heat exchangeable property of foam structures would minimize the necessity of heat exchangers. The use of foams is seen to benefit propulsion system components such as engines, combustion chambers (transpiration cooling), ducts, and flanges.



Point of Contact

Binayak Panda/ED33
Phone: 256–544–6349
Email: Binayak.Panda-1@nasa.gov

High-strength and Compatible Aluminum Alloy for Hydrogen Peroxide Fuel Tanks

Benefits

Currently, aluminum alloy 5254 is the state-of-the-art material for HP compatibility, but its yield strength is very low and may not be suitable for lightweight fuel tanks for Hyper-X vehicles. It is anticipated that the new alloy will be compatible with HP and roughly three times stronger than conventional Al–5254. The new high-strength and HP-compatible alloy could represent an enabling material technology for NASA's Hyper-X vehicles, where flight weight reduction is a critical requirement.

Objective

The objective of this effort is to develop a new high-strength and compatible aluminum alloy for hydrogen peroxide (HP) propellant for NASA Hyper-X vehicles' fuel tanks and airframe structures.

Approach

This proposed effort will demonstrate a proof of concept in which a new alloy will be developed that will enhance tensile strength while maintaining HP compatibility. The alloy development strategy is to scientifically select certain rare earth and transition metals with unique electrochemical properties that will not react as catalysts for HP at the atomic level. Such elements will be added to the aluminum alloy and the mixture will be cast and rolled into thin sheet metals. Test coupons will be machined from sheet metals for HP testing and mechanical testing. In addition, the ability to weld the new alloy using either plasma arc or friction stir welding will be explored.

Deliverables

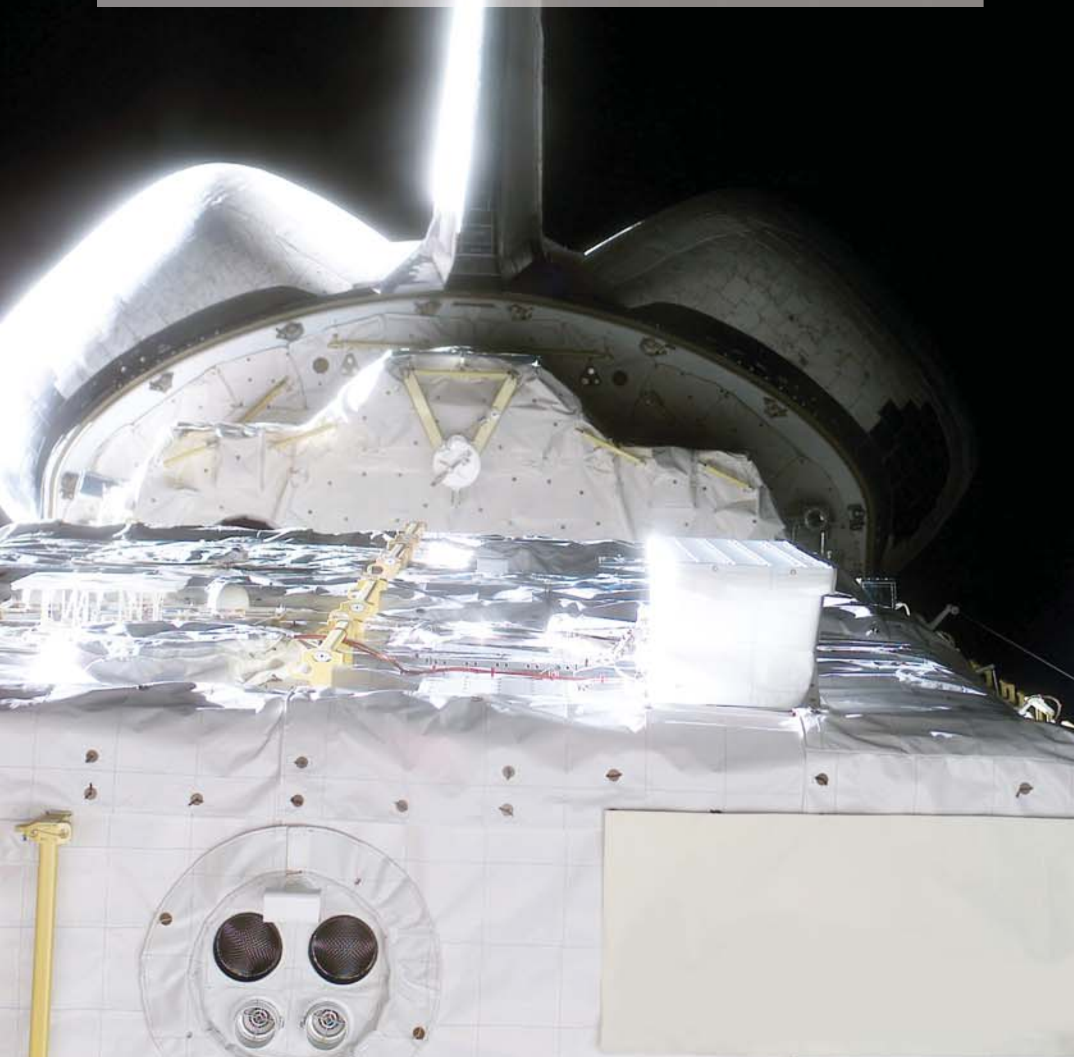
- Deliverables will include the filing of patent applications, test coupons, data for HP environment compatible testing, mechanical and physical properties database, friction stir welding database, and a final report.

Point of Contact

Jonathan Lee/ED33
Phone: 256–544–9290
Email: jonathan.lee@nasa.gov

Additional ED Technologies . . .

As we have seen, much of the technology development work within the Engineering Directorate is accomplished in support of the Technology Thrust Areas. However, additional technology development activities are undertaken that reflect pockets of expertise within ED that are not cleanly categorized within the Thrust Area structure, but they are no less important in the support that they provide to their customers. Indeed, ED focuses a portion of its new technology development efforts in support of its customers within the Program Offices at MSFC and NASA that fall outside the scope of the Thrust Areas. Such work performed within the four Departments of the Engineering Directorate—Avionics; Structures, Mechanics & Thermal; Materials, Processes & Manufacturing; and Engineering Systems—supports a varied and diverse range of customers.



ENGINEERING DIRECTORATE

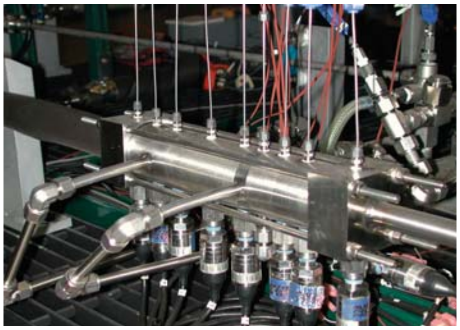
Marshall Space Flight Center
Huntsville, AL

http://etdo.msfc.nasa.gov

Two-phase Flow Boiling Facility for Jet-pump Demonstration

Benefits

- The jet-pump has no moving parts, good resistance to cavitation, and very low noise and vibration levels as compared to mechanical pumps.
- The jet-pump is heat-actuated instead of power-actuated. This means that waste heat can be dumped into the fluid system to operate the pump instead of utilizing additional system power to operate the pump (that in turn has to also be rejected by the thermal control system).
- Two-phase loops have many advantages over a single-phase system. Due to latent heat of evaporation in a two-phase coolant, much more waste heat per unit of flow can be transferred, thus resulting in a more efficient, lower mass cooling system.
- Nearly isothermal conditions can be provided to the cooled equipment even with variable heat loads.
- The heat transfer coefficients associated with two-phase processes are much higher than convective liquid heat transfer coefficients, which also improves the efficiency compared to single-phase.



Point of Contact

John Sharp/ED26
Phone: 256–544–5156
Email: john.r.sharp@nasa.gov

Objective

The objective of this effort is to demonstrate the successful operation of theoretical two-phase jet-pump technology utilizing a flow boiling facility with Freon-113 working fluid.

Approach

A jet-pump is a thermodynamic system that utilizes nozzles, subcooled liquid sprayers, mixing chambers, and a diffuser section to generate a pressure rise. This in essence converts heat energy into pumping power. Therefore, waste heat from a spacecraft system could be utilized to drive the pump. A test-bed has been constructed to reproduce analytically derived operating conditions (liquid vapor quality, pressure, flow-rates, etc.) as a proof-of-concept of the jet-pump technology. Avionics waste heat is simulated via the boiler (heaters around the copper tubing) and space radiator cooling is simulated with the external Freon-12 refrigerator system. A mechanical pump is used to achieve start-up conditions, then pressure and temperature sensors record the jet-pump performance.

Deliverables

- An operational test-bed facility capable of demonstrating the jet-pump performance by test.
- A final report documenting the test data and conclusions.

Development of a Thermoacoustic Heat Engine for Spacecraft Power Generation

Objective

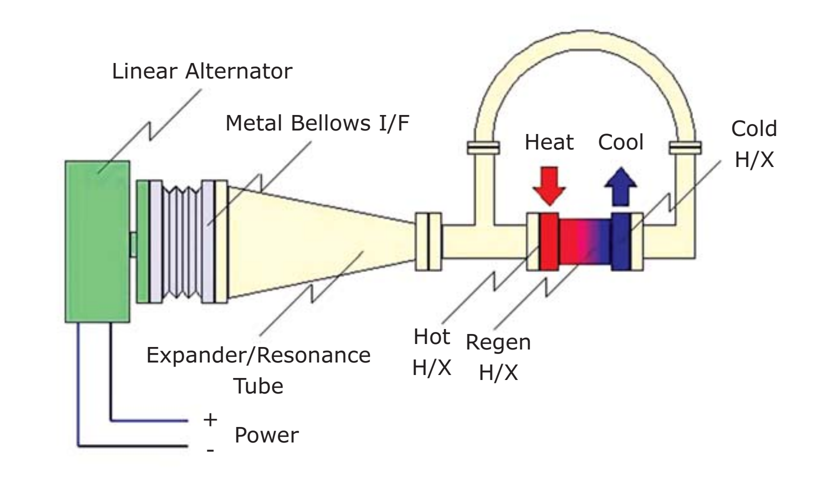
The objective of this effort is to design, build, and test an inherently reliable and efficient breadboard thermoacoustic heat engine for spacecraft power generation.

Approach

The first phase of this effort is to develop thermal/fluids mathematical models of a thermoacoustic heat engine process in SINDA/FLUINT. This modeling will be used to optimize and size a breadboard design that will induce a resonant acoustic wave via a thermal gradient across the stack. Then, the hardware will be built and operated with the objective of converting heat energy into acoustic energy that could be converted to electrical power via a linear alternator or piezoelectric conversion process. The test results will be used to correlate the math model for use in assessing alternate design configurations that would be suitable for large-scale space-based systems.

Deliverables

- A breadboard thermoacoustic heat engine capable of converting heat energy into electrical power.
- A final report documenting the thermal/fluid analyses and design of the breadboard heat engine as well as test results and conclusions.



Benefits

- This innovative technology takes advantage of the phenomenon that a thermally induced traveling acoustic wave can be used to reliably and efficiently drive a linear alternator for power conversion.
- The inherent reliability of a thermo-acoustic heat engine is derived from a design in which there are no moving parts aside from a linear alternator.
- Acoustic heat engine technology could find direct application to the Nuclear Space Initiative (NSI) program, where heat from nuclear reactors is converted to electricity for the propulsion system and spacecraft bus.
- There are several options for power conversion ranging from thermoelectrics (high reliability/low efficiency) to higher efficiency (and possibly lower reliability) Brayton and Stirling cycle heat engines. Thermoacoustic conversion technology offers both high reliability and efficiency with the potential to operate at higher temperatures than existing power conversion technologies.
- Efficient and reliable spacecraft power generation will potentially benefit all MSFC product lines.

Point of Contact

John Sharp/ED26
Phone: 256–544–5156
Email: john.r.sharp@nasa.gov

Thermal Vacuum Test Hardware Development

Benefits

This system will operate through very extreme range typically required for thermal/vacuum environmental testing while allowing for precise test-article temperature control. Typical approaches utilize man-in-the-loop control of liquid nitrogen-fed heat exchangers, which result in very long tests and are prone to over- and under-temperature during cycling. This system will give vastly improved test times and precise temperature control. Since the Environmental Test Facility tests hundreds of components a year from all MSFC product lines and external customers, this would allow for significant increase in the number of tests that could be performed and thereby reduce the test cost to the customer.

Objective

Develop efficient and automated test hardware for direct interface test article temperature control in thermal vacuum environmental chambers.

Approach

Thermal/fluids analyses were performed with SINDA/FLUINT software to size a closed-loop system capable of controlling an interface plate between 150 ˚C and 200 ˚C. This involved designing a concept of the hardware and sizing the various components for the general requirements typically needed for thermal-vacuum chamber operations. In addition to generating a system-level design, detailed thermal/fluids modeling was performed to determine an optimized interface plate internal flow pattern. In order to ensure proper manifolding, computational fluid dynamics (CFD) modeling has been performed on the highly turbulent entry region. Flow visualization tests are underway on a sectional demonstrator to give confidence in the CFD results. Additionally, heat transfer performance tests are planned to verify the bulk heat transfer capability of the interface plate design. The full system design consists of a gaseous nitrogen blower, a three-way control valve to control the split in flow between an in-line heater leg and the interface to the cold sink. This control system will provide precise computer controlled temperature on the in-chamber test article. The overview of cart-mounted components is shown in the figures, as well as the summary of flow visualization testing performed to date.

Deliverables

- Functional closed-loop control system for achieving 150 ˚C to 200 ˚C coldplate interface temperatures via automated control system with characterization testing in Thermal Development Facility.
- Flow visualization and thermal characterization testing of optimized interface plate design.

Point of Contact

John Sharp/ED26
Phone: 256–544–5156
Email: john.r.sharp@nasa.gov