Revolutionary Technologies for Leak Repair in Space Exploration Vehicles and Space Habitats

NIAC Student Fellows Prize Report
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Space Debris

- The US Space Surveillance Network currently tracks 13,000+ pieces of manmade and natural debris over 10 cm wide.

- Approximately 7% of this debris orbits at the same altitude as the International Space Station and Space Shuttle (~300 km).

- There is currently no capability to track debris smaller than 10 cm.

- Even tiny pieces of debris traveling at 17,000 mph will cause significant damage upon impact.

1 mm debris impact damage on STS-007 window
Current Method of Leak Detection

It is a slow, tedious and potentially hazardous procedure to locate a leak source within the entire pressurized environment using an analog pressure sensor. This task will become increasingly more difficult as the Space Station continues to grow in size or in larger space habitats of the future.

Above: Schematic of the ISS after the addition of the Columbus module

Right: Handheld pressure sensor used by crew to detect leaks
(NASA Johnson Space Center)
Immediate Determination of Leak Coordinates

- Grid of piezoelectric pressure sensors
- Sampling Rates on the order of hundreds of kHz
- Natural quartz crystals produce a voltage when the diaphragm is flexed (pressure changes)
- Built in acceleration compensation make them unresponsive to shock and vibration of the system
Determining the Leak Coordinates

\[ (x_L, y_L) = \text{Leak Coordinates} \]
\[ (x_{SN}, y_{SN}) = \text{Sensor N Coordinates} \]
\[ V_p = \text{Velocity of Pressure Wave (346 m/s)} \]

\[ d_2 = v_p \Delta t_{s1,s2} = \sqrt{(x_L - x_{S2})^2 + (y_L - y_{S2})^2} - \sqrt{(x_L - x_{S1})^2 + (y_L - y_{S1})^2} \]
\[ d_3 = v_p \Delta t_{s1,s3} = \sqrt{(x_L - x_{S3})^2 + (y_L - y_{S3})^2} - \sqrt{(x_L - x_{S1})^2 + (y_L - y_{S1})^2} \]
\[ d_4 = v_p \Delta t_{s1,s4} = \sqrt{(x_L - x_{S4})^2 + (y_L - y_{S4})^2} - \sqrt{(x_L - x_{S1})^2 + (y_L - y_{S1})^2} \]
The most Simple and Fundamental Solution
For Automatic, Repeatable Leak Repair

An ultra-light sensor/textile-like liner composed of carbon nanotubes or a similar material is used to completely cover the inner wall of the Space capsule.

Upon impact and subsequent damage, the decompression causes the liner to be sucked out of the leaking orifice.

Nanotubes are extruded through the orifice creating a “plug” and causing the leak to be repaired fast and efficiently.
Carbon Nanotube Textiles

• Carbon nanotubes are one of the most promising new materials in textile science.

• Researchers at CSIRO have succeeded in spinning yarn composed of pure carbon nanotubes

• This yarn is one of the most highly anisotropic materials ever produced
Carbon Nanotube Textiles

- As the nanotube fibers get sucked into the hole, the textile will form a plug consisting of many nanotubes, mostly aligned in the same direction.

- According to experimental data, a densified stack of 18 nanotube sheets had a strength of 175 MPa/(g/cm³) while ultra-high strength steel only has a strength of 125 MPa/(g/cm³).

- These fibers also have excellent electrical conductivity.

Scientists can now produce nanotube fibers of any length, previously 20 cm was the longest length ever produced.
We are in a meteor belt and hope we can get through this safely. Our mission success depends on passing this test. Piezoelectric sensors have sensed the pressure wave. The leak is plugged. The sensors will automatically reset. This is indeed a revolutionary technology. Repeatability adds to the overall reliability.

WOW!!!

That was amazing how fast the leak was fixed. Reliability is the fundamental issue. Let’s hope any future impacts are fixed as reliably as this one!!

The approach is simple and is the most fundamental solution to automatically fix leaks in any Space environment. Carbon nanotube-based textile-like liners provide instant leak repair. Close proximity of nanotube acoustic sensors to the Inner wall of the Space capsule provides capability to detect micro-cracks as they emerge during impact with unidentifiable Space objects.
Leak Repair MicroBot Swarms

A revolutionary concept for repairing leaks caused by impact of CEVs and CLVs with Space debris and micrometeorites.
Swarm Technology

- Once a leak occurs, the sensor net computes the leak source coordinates
- A mother sensor housing inflatable Repairbots prepares them for dispatch
- Preparation includes programming the leak coordinates into the built-in RFID tags
- Repairbots are then inflated thereby providing air-jet propulsion to navigate to the leak source
- Once the crew have donned safety glasses a Red laser beam is pointed at the leak coordinates
- Using narrowband photo-detectors filtered to only see red light, the Repairbots travel towards the leak source
- Navigation to the leak source involves acoustic sensing, molecular water sensing, and air current sensing
Repairbot Features

- Fog Port
- Nanotube Air Current Acoustic sensor
- Acoustic sensor
- Nanotube Molecular Water sensor
- Glue-Foam Ports
- Vector-Thrust Propulsion
- Low, Medium, High Frequency Membrane acoustic sensors
- Narrowband Photodetectors
- Air Inlet
- RFID Tag
- Glue-Port Pull Release
How does Repairbot navigate towards the leak?

- Small radioactive source ionizes surrounding air (Americium-241)
- Radioactive source is enclosed by an ion detector array
- Only the ion detectors “downwind” of the radioactive source will measure the increase in ion concentration in the air

Ionized air stream flowing towards a leak source
Carbon nanotubes are active charge collectors that can be used for detecting air currents by tracking a source of ionized air. Provides repairbots a means to navigate in microgravity environments along the paths of maximum air currents.

Single Wall Nanotube (SWNT)
Double Wall Nanotube (DWNT)
Multi Wall Nanotube (MWNT)

Single Wall Nanotubes detect water molecules from fog release and condensation caused by atmospheric air leak

http://msl.stanford.edu/Files/nl034064u.pdf

Provides repairbots a means to navigate in microgravity environments along the paths of maximum air currents.
Mother sensor discharges Repairbot. A system-on-a-chip that combines vision-acoustic-molecular water sensing provides navigation control. Narrowband photodetectors provide lock on the illuminated laser target and carbon nanotube acoustic and molecular water sensors track air currents and moisture condensation.
Repairbot generates Fog which saturates the moisture condensation funnel caused by escaping ambient air in to the vacuum of Space. Carbon nanotubes sense Molecular Water and a system-on-a-chip provides navigation control to Repairbot’s miniature vector-thrust air-propulsion system.
Upon reaching the leak source the sacrificial Repairbot is sucked in to the orifice. RFID tracking confirms arrival of Repairbot at the leak source.

Repairbot is pulled through the orifice and is entombed inside the hardened glue-foam. This eliminates any possibility of creating “new” Space debris.
Self-Vulcanizing Material

NASA Johnson Space Center and White Sands Testing Facility are testing a “Model 655 Semkit” which is to be a manually deployed injector-type sealant foam package for repairing leaks.
Closing Remarks

• We have in principle shown how a very simple concept for leak detection and repair may be implemented and expanded upon to include swarm technology to greatly enhance safety to humans in Space.

• We have also demonstrated through scientific reasoning how such a simple concept has the potential for the development of several new and revolutionary nanoscale sensor technologies.

• We have identified a broad area of research and development aimed at providing the “highest” level of safety to human explorers in Space.
Chronological list of Publications & Presentations


3) “Dynamic Sensor Net and Sensor Swarm to Locate and Repair Leaks in Pressurized Environments”, PowerPoint handout at the NIAC meeting/poster presentation, Denver, October 2005

4) “Dynamic Sensor Net and Sensor Swarm to Locate and Repair Leaks in Pressurized Environments” Poster presentation at the NIAC meeting, October 2005

5) “Advancements in the Concept of Sensor Swarms to Repair Pressure Leaks”, NIAC November Status Report, November 2005

6) “Micro-robots for repair of atmospheric leaks in CEVs and CLVs caused by impact with Space debris”, JPL/DRDF Proposal submitted by JPL in collaboration with USC, December 2005

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Thank You for viewing this PowerPoint presentation

If you have any comments and/or suggestions you may send them to: jfroncze@nmsu.edu

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