Radiation shield for deep-space travel inspiredby fiddler crab’s shell compositio...

Science, Astronomy

Sending humans into outer space to destinations farther awaythan we have ever been before will result in new innova-tive ideas to solve the big challenges that lie ahead. Oneof those challenges is protecting the spacecraft and the astro-nauts from the deadly radiation in outer space. This concep-tual study focuses on the use of a new material inspired byfiddler crabs for radiation shields. Fiddler crabs can survivehigh doses of radiation whichit is considered to be becauseof their protective shell and exoskeleton. Copying the com-posite structure of calcium-carbonate in a matrix of a glu-cose derivative polymer from the fiddler crab’s shell couldbe the solution to shield against radiation. Using a materiallike this could also act as a passive thermal control for thespacecraft.

Introduction

The last time humans have travelled to deep-space destina-tions was in 1972. Apollo mission 17 was the last timeNASA took their astronauts beyond earth’s proximity to themoon. But we are standing at a new era in human spacetravel. In the upcoming decade, we will be sending humansfarther in space than we have ever been before. Both NASAand SpaceX have concrete plans for missions to the moon(either as another moon exploration mission or just a fly-by) and even to our neighbouring planet in the Solar System: Mars. These ambitious missions will face huge engineeringchallenges. Astronaut’s safety will be the number one prior-ity and a safe return to earth is crucial for a successful spaceprogram. One of the biggest problems with sending humansinto deep-space compared to keeping humans in near-earth-orbit as we have been doing the past 50 years is protectingour astronauts from hazardous radiation which they will beexposed to for a long duration of time. A report from NASAdescribed this radiation exposure was a very serious prob-lem for the Apollo missions in the previous century. Thisconceptual study looks at a radiation shield for spacecraft in-spired by the peculiar characteristics fiddler crabs show whenexposed to high radiation.

Radiation problem in deep-space travelOuter space is filled with high charge, high velocity parti-cles which mostly originate from solar flares and solar wind. Earth’s magnetic field acts as a big shield against these highlycharged particles which keeps us protected from this ra-diation in all of our activities on earth and in low-Earth-orbits (LEO). The problem occurs when a spacecraft wantsto escape the proximity of earth and move into deep-space.

Earth’s magnetic field makes all the charged particles tobounce away. This effect causes an area of an extremely highconcentration of this particles just inside of Earth’s magne-tosphere. There are two of these so-called Van-Allen radi-ation belts. The inner radiation belt starts at an altitude of600 miles and ends at about 1, 000 miles above Earth’s sur-face. The outer radiation belt is located from 8, 000 miles to37, 000 miles above Earth’s surface. Spacecraft on their wayto the Moon, Mars or other deep-space destinations have tocross these radiation belts. The high concentration of ener-getic electrons and protons form a very high risk for both hu-mans and electronic equipment aboard the spacecraft. Thick steel shields have been used in the Apollo missions to ab-sorb a large amount of this radiation. This solution was farfrom perfect; the astronauts and electrical equipment werestill exposed to very high radiation inside the spacecraft andthe steel shield were extremely heavy. Every pound counts inspaceflight. Every pound needs to be lifted up by the rocketwhich launches the spacecraft to orbit and every pounds requires more fuel to be added in the rocket. This fuel itselfneeds to be lifted up which requires even more fuel. It is therefore of utter most importance to keep the spacecraft'stotal weight as low as possible.

A spacecraft on its way to deep-space only takes a cou-ple of hours to cross these Van-Allen radiation belts. Butthe problem is not gone after the spacecraft has escaped theradiation belts. Because Earth's magnetic field is no longershielding the deep-space radiation, the spacecraft will still beunder a constant exposure of a significant amount of radia-tion. Both a short time exposure to extremely high radiation (inside the Van-Allen radiation belts) as a long time expo-sure to relatively low radiation (which is present everywherein deep-space) can do much damage. Although the radiationin deep-space is nothing compared to the radiation inside the Van-Allen belts, it can be even more troubling because of thelong exposure time. A journey to Mars would for exampletake over 8 months.

Radiation shield based on Fiddler Crabs

D. W. Engel studied the radiation sensitivity of severalcrab types and published his article in the scientific journal Chesapeake Science. Several species of crabs were exposed to an increasing amount of radiation for the periodof 60 days. Whereas most of the crab species died at what was considered a lethal doses of radiation, estimated in comparison to other animals, fiddler crabs seemed to beable to survive these extremely high radiation exposures. Engel studied merely the deadly effects on crabs and wasnot trying to explain why these fiddler crabs were so muchbetter in surviving these high radiation exposures. Though itwas not the purpose of his study to explain these results, he does propose a hypothesis for this effect. He suggests thatthe most logical reason for the high radiation tolerance mustbe because of the specific shell composition these fiddler crabs have. Although there is not much other research performedon the shell structure and composition of fiddler crabs, this particular property of shielding against radiation can be of huge interest for deep space missions. A shield built in asimilar way as fiddler crabs shells could most likely have better radiation protection than existing steel shields. But thebiggest win in using a shell-like structure can found in thedecrease of weight. Crab shields are extremely lightweightstructures which is another great characteristic for space-flight applications. The use of crab shell like shields forspacecraft is in this initial study extremely promising.

Fiddler crab shells are structured similar to carbon-fiber. Mineralized protein-based fibers are arranged perpendicularto the layer below to create a natural composite. To provideeven more strength to the structure, cylindrical canals are located normal to the surface of the shell. Because of thisspecific layout of fibers the structure is considered to havean-isotropic mechanical properties, meaning the mechanicalproperties are not direction-based. The material of the fibers consists of a combination between calcium-carbonateand a polymer derivative of glucose, called Chitin. Thecalcium-carbonate is the basis for the fibers which are basedin a matrix of the long chain highly mineralized Chitin. Even though men-made composites are generally notbuild up of these chemical components, it should be possibleto recreate a similar material as the fiddler crab shells. The use of fiber composites has been around for many yearsand is a field of material science that has been studiedand perfected within the Aerospace industry. Adopting the chemical composition of fiddler crab shells should bepossible to build radiation shields with similar radiationtolerance properties as the fiddler crabs have. Another very interesting material characteristic of thefiddler crab shells is that they insulate the crab to survive ex-treme temperatures (both extreme cold as extreme heat).

Radiation shields would most likely have similar propertiesfor these temperature ranges. This is an additional featureof the crab inspired radiation shields, which is extremelyuseful in deep-space travel. Temperatures in outer spacetypically range from -200 degrees Celsius up to 200 degrees Celsius. Spacecraft are equipped with active thermal controlsystems (TCS) to keep the electronics in an operable tem-perature range and to regulate the temperature in the crewcompartments. Having the passive temperature control fromthe insulation of the radiation shielding would save a lot inboth weight and development costs of conventional thermal control systems.

Conclusion

With the ambitious missions of sending humans to the Moon, Mars and other deep-space destinations, a big engineeringchallenge need to be overcome in protecting the astronautsand the spacecraft electronics from radiation damage. The concentration of high charged particles is particularly high in the Van-Allen belts which need to be crossed to set sailfor the deep-space destinations. The danger continues af-ter these radiation belts because of the background radiationthat is always present in outer space which the astronautswill be exposed to for very long periods of time. A very promising solution in this radiation problem could be foundin the structure and chemical composition of fiddler crabs.

These crabs seem to survive what would be considered tobe lethal doses of radiation. Using a material inspired byfiddler crab shells would be a very effective radiation shieldfor spacecraft. The crab shells consist of calcium-carbonate fibers in a matrix of a long-chain minerilized polymer called Chitin. This results in a strong light-weight structure, whichare two other requirements for Aerospace applications. Hu-mans have mastered the skills to build similar fiber compos-ite structures which are already widely used in the Aerospace industry. Combined with the knowledge of chemistry, hu-mans should be able to produce a material very similar tothese fiddler crab shells. Apart from the radiation blocking properties, the exoskeletons cause fiddler crab to be able to survive in extreme temperatures. This side-effect would beuseful to protect spacecraft not only from the hazardous radiation, but also from the extreme temperatures in outer space.