NASA Scientists Develop World's Smallest, Lightest, High-Performance Mass Spectrometer

NASA-supported researchers have developed the world's smallest and lightest high-performance mass spectrometer, a complex instrument that is used in space and also has many important scientific applications on Earth. The device is a prototype for a new generation of miniature instruments that could produce significant savings for the space program.

On long-duration human space missions, the detection of trace levels of toxic chemicals in the air and water is crucial to astronaut survival. Mass spectrometers—powerful instruments with an abundance of applications on a space mission—play an important role in monitoring the environment of a spacecraft, including the level of trace gases, the microbial content of a spacecraft's air and surfaces, and the quality of on-board drinking water.

By analyzing a small sample of any substance, a mass spectrometer can determine the substance's chemical composition. "It is a workhorse instrument—there is one on almost every robotic space mission," says Ara Chutjian, Ph.D., leader of the Atomic and Molecular Collisions Team at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California.

The mass spectrometers currently deployed on space missions are large, heavy instruments. For example, the mass spectrometers being flown on the Galileo mission to Jupiter and the Cassini mission to Saturn weigh 20 to 25 pounds and consume about 25 watts of power.

Chutjian and his colleagues have developed a miniature high-performance mass spectrometer that is the smallest and lightest in the world. The sensor itself is just three inches long, weighs about a quarter pound, and consumes 12 watts of electric power. The entire system, including all electronics, pumps, microprocessor, and packaging, weighs about three pounds and consumes 15 watts.

Instrument size and weight are crucial factors that affect the duration and cost of space missions. Large, heavy instruments slow down a spacecraft, increasing the time it takes to reach far-flung destinations. The development of small, lightweight instruments with capabilities approaching those of their larger counterparts could significantly shorten, and reduce the cost of, long-duration space missions.

"Volume, mass, and power are all at a premium on a spacecraft," says Chutjian. "If the instruments are small, there is more room for the astronauts, more room for experiments, and more space to store consumables for a longer mission."

Delivery to the International Space Station

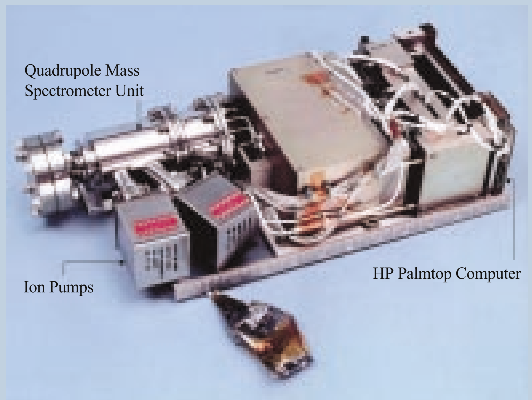
The miniature mass spectrometer, named the Trace Gas Analyzer (TGA), was built by Chutjian and his colleagues at JPL and at Oceaneering Space Systems in Houston. It was delivered to the International Space Station (ISS) in February 2001. Its primary use aboard the ISS is to detect leaks of ammonia and rocket propel-

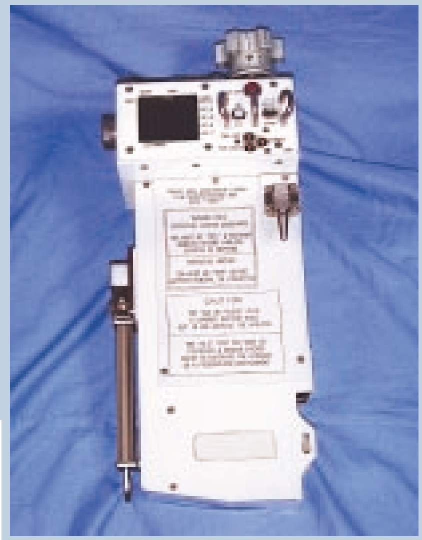
Trace Gas Analyzer (TGA) in use during a space walk, in an artist's depiction. The TGA uses a miniature quadrupole mass spectrometer to seek tiny leaks external to the space station. The TGA is currently stored aboard the space station and available for use.

lant, as well as any leaks of air from seals and micrometeorite holes in the spacecraft structure.

Ammonia is used to cool the space station, maintaining a consistent on-board temperature as the craft travels through the temperature extremes of low-Earth orbit. (Objects in direct sunlight in near-Earth orbit can heat up to about 115° F. In shadow, they can cool down to around -15° F.) As astronauts disconnect and reconnect the external ammonia lines to add new modules to the space station, ammonia may leak from the “quick-disconnect” fittings. Such a leak would cause a rise in on-board temperature and could result in human discomfort and instrument malfunctions. To check for leaks, an astronaut straps the trace gas analyzer onto his or her chest pack before a space walk. Trace amounts of escaping gas register on a visual display atop the TGA, indicating to the astronaut any potential safety risk.

For its role as a cabin-atmosphere monitor, the mass spectrometer has been combined in the laboratory with a miniature gas chromatograph, an instrument that separates complex mixtures of gases before they are analyzed by the mass spectrometer. The combined gas chromatograph-mass spectrometer (GCMS) system weighs about four pounds and is 16 inches long, nine inches wide, and six inches high.





(Left) Basic components of the quadrupole mass spectrometer unit (3 in long) within the Trace Gas Analyzer (TGA) (15 in long). (Right) The TGA prior to launch on STS-98.

On a human mission to Mars, a GCMS would be essential to continuously monitor air in the spacecraft cabin to detect any accumulation of dangerous gases such as carbon monoxide, benzene, or formaldehyde, explains Chutjian. With a suitable interface, the device could also be used to study the chemical composition of rocks, ice, and dust collected from a Martian or asteroid surface. On robotic planetary missions such as Galileo and Cassini, mass spectrometers are used to study the atmospheric composition of the planets and their satellites.

Applications of Mass Spectrometers on Earth

On Earth, mass spectrometers are widely used in pollution control activities. “The federal Environmental Protection Agency uses them to monitor levels of contamination at Superfund sites and levels of emissions from factories,” Chutjian notes. However, the large size and high cost of these instruments means that currently such monitoring can be performed only intermittently, with the samples often brought to a central laboratory for analysis.

In the future, small, inexpensive, energy-efficient mass spectrometers could be used for continuous monitoring of contaminants or emissions at more on-site locations, says Chutjian. “You could use them for smog detection or you could put one down a well to monitor the quality of underground drinking water.”

Chutjian and his colleagues are now working on a second-generation miniature mass spectrometer with three times the resolution and 50 times the sensitivity of the current model.

References

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The Jet Propulsion Laboratory is the lead U.S. center for robotic exploration of the solar system. Development of the miniature mass spectrometer was funded by NASA and performed in collaboration with the NASA Johnson Space Center in Houston and Oceaneering Space Systems, a Houston company, which provided several electronic modules, designed and built the instrument’s housing, and conducted an extensive series of preflight tests.