Measurement of Surface Erosion From Discoverer 26[1]

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DO THE molecules of the upper atmosphere which bombard a satellite erode its surface enough to affect its operational life? Since the first satellite was launched in 1957, this type of erosion, known as sputtering, has been considered as a possible problem to a vehicle in a low orbit where the atmosphere is relatively dense. Direct measurements in space needed to answer this question have eluded researchers because of the lack of sensitive satellite instrumentation. By use of a specially designed satellite-borne erosion gage developed at General Dynamics/Astronautics, the first direct measurement of erosion has been made with the flight of Discoverer 26 on July 27, 1961. From the results of this flight, it is now possible to put an upper limit on the sputtering erosion of a gold surface in space. This flight also initiated a series of measurements to be made on the wearing away of surfaces in space by other means, such as by outgasing, solar wind bombardment, and impacts of micrometeorites.

The operation of the gage is based on the crystal oscillator method (1),[5] which is used in the laboratory to measure erosion or deposition of material from a surface by means of the change in resonance frequency of a quartz crystal. The gage is cylindrical in shape, 3.5 in. long and with a 1-in. diam. It consists of two 10-Mc quartz crystals and electronic circuitry. The crystals are designated as a test crystal and a reference crystal. The test crystal is located so that its front surface will be in a space environment. Erosion of its plated surface results in an increase in its resonance frequency. Various materials such as gold, aluminum, or silicon monoxide can be plated onto the crystal. The reference crystal, which is shielded from the micrometeorite and molecular bombardment by the test crystal, is plated with gold, which does not outgas any significant

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amount in a hard vacuum. The reference crystal is provided to beat the test crystal frequency to the audio-frequency range for telemetering purposes. By matching the two crystals, the frequency temperature dependence of the gage can be kept less than 1 cycle/°C over a 60°C range. For special purposes, the crystals can be mismatched and the gage used as a temperature probe.

The output beat frequency of the gage is set at 500 cps and increases 1 cps per millimicrogram of plating eroded from the test crystal. In terms of plating thickness, a 1-cps increase represents an average erosion of 0.04 Å from a gold surface. The output frequency of the gage is converted to a low frequency square wave by a scaler before telemetering.

Two gages were flown on Discoverer 26. A control gage was put on board to determine what effects a space environment would have on the gage as a unit when the test crystal was shielded from direct particle bombardment. A second gage was used to measure the erosion rate of a plated gold surface. The surface was exposed to space through $\frac{2}{3}\pi$ or by a circular window of $\frac{1}{8}$-in. diam. Since the Discoverer was oriented in space, it was possible to direct the gage so that bombardment by particles of the upper atmosphere was at normal incidence to the plane of the gold surface.

Fortunately for the erosion experiment, Discoverer 26 was launched at dusk. Because the satellite was attitude controlled, one side was always turned away from the sun. The gages were mounted on the shady side and in effect were temperature controlled. If the gages had been periodically exposed to the sun, which would have happened for a launch earlier in the day, the sensitivity of the erosion measurement would have been lowered somewhat because the gage output frequency is temperature dependent.

The frequency output of the erosion gages during the flight is shown in Fig. 1. Crystals in the control gage were mismatched so that the temperature of the gage could be determined from its frequency output. From the first orbit until the ninth, its frequency fell rapidly with temperature until it reached −40°C, the frequency-temperature turnover point of the crystals. From then on the frequency changed less rapidly as the temperature slowly decreased to −110°C. It took four days for the temperature of the gage to stabilize. The temperature information received from the gage checked with measurements made on the skin of the satellite.

The crystals in the test gage were matched to minimize frequency-temperature changes. It experienced only about a 25-cycle change during the first four days of flight because of decreasing temperature while the control gage was undergoing wide frequency excursions. The jump in the frequency of the test gage during readout of the fortieth orbit is attributed to a micrometeorite impact causing a momentary heating of the test crystal.

In analyzing the data from the test gage, only measurements after the sixtieth orbit were used to eliminate the effect temperature changes have on the output frequency of the gage. Also the measurements will be uncomplicated by particle-particle interactions associated with the satellite outgassing cloud and the upper atmosphere. It has been reported by experimenters measuring ion densities in space from Discoverer satellites that it took several hours before their detectors registered expected values. They attribute this to the outgassing cloud partially shielding the satellite from direct bombardment by the upper atmosphere.

The erosion rate for the gold test surface is shown in Fig. 2. The rate is 0.2 ± 0.1 Å/day. This rate represents an upper limit for a gold surface in a space environment. Discoverer 26 was in a low orbit, perigee 230 km and apogee

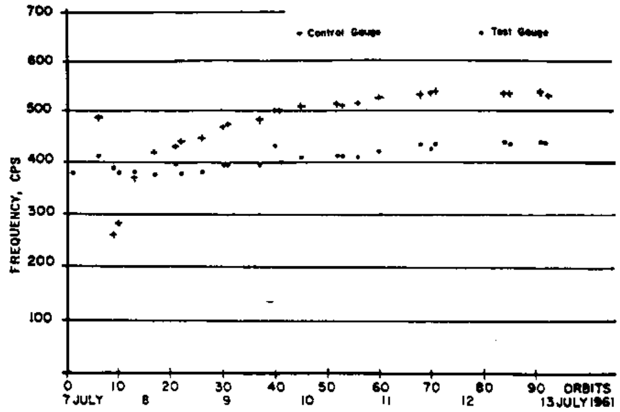

Fig. 1 Frequency output of erosion gages during flight of Discover 26

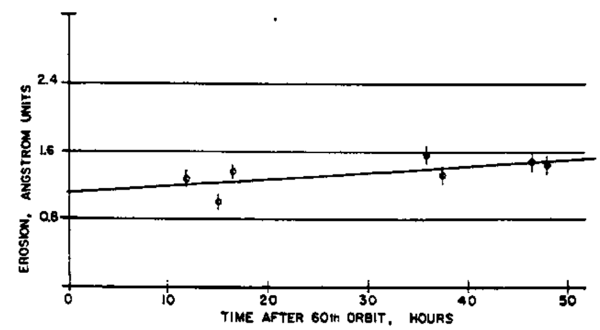

Fig. 2 Erosion of gold in space

810 km. For higher orbits, the particle density of the upper atmosphere decreases markedly, and sputtering, which probably represents the major factor of the erosion measured here, would fall to an insignificant amount.

It is interesting to assume that the erosion was primarily the result of sputtering and set an upper limit on the sputtering rate of gold. From this, it can be judged whether sputtering will be a problem to a satellite. In making the calculation, the composition of the atmosphere (2) and the time the Discoverer spends in the denser regions were taken into account. The upper limit of the sputtering rate μ, the number of surface atoms ejected per incident molecule, is found to be

$$\mu < 5 \times 10^{-6} \text{ atom/molecule}$$

From this result it does not appear that a satellite will be affected much by sputtering.

A second measurement of the erosion of gold was made on Discoverer 32 on Oct. 13, 1961. Preliminary analysis of the data from this flight substantiates the results given here.

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