NATURAL HAZARDS OF THE SPACE ENVIRONMENT

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Spacecraft in Low Earth Orbit (LEO) are subject to numerous environmental hazards. Here I'll briefly discuss three environment factors that pose acute threats to the survival of spacecraft systems and crew: atmospheric drag, impacts by meteoroids and orbital debris, and ionizing radiation.

Atmospheric drag continuously opposes the orbital motion of a satellite, causing the orbit to decay. This decay will lead to reentry if not countered by reboost maneuvers. The drag deceleration is directly proportional to the density of the thin atmosphere through which the spacecraft passes. During the maximum in the 11-year solar activity cycle, increased solar ultraviolet radiation heats the atmosphere causing it to expand and to increase the density at a given altitude. Figure 1 shows solar activity during the past thirteen years. The mean density at a given altitude tracks this solar activity curve. Meteoroids and orbital debris (M/OD) pose the obvious hazard of penetrating spacecraft surfaces, damaging external and internal equipment; decompressing manned modules, propellant tanks and lines, and batteries; and generating plasma pulses that can lead to failure of electronic components not directly penetrated. Meteoroids arrive from the zenith hemisphere, the Earth providing shielding to the satellite from below. There are two meteoroid components: the so-called sporadics, which produce a constant background flux of particles, and the streams, which produce the meteor showers seen regularly on certain dates throughout the year. Most meteoroids are small, low-density (~1 g/cm^3) objects, but they impact at high speeds, from 16 to 72 km/s, and so may have high kinetic energy.

Orbital debris is a by-product of man's activities in space, and consists of objects ranging in size from miniscule paint chips to spent rocket stages and dead satellites. As a collision threat, debris is always present, and debris objects are most likely to arrive roughly in the local horizontal plane of a satellite, with peaks in the flux distribution at about 30 to 60 degrees either side of the satellite's velocity direction, as shown in Figure 2. Debris particles are modeled as having the density of aluminum, 2.7 g/cm^3, and having collision velocities from 2 to 14 km/s. The spatial density of debris particles at a given altitude will vary with the atmospheric density there, and so will be a complex function of the solar activity cycle and the rate of debris introduction from above (by orbital decay) and from debris producing events, such as collisions.

The countermeasure to both meteoroids and debris is to furnish spacecraft with shields to break up the incoming particles before they can penetrate important structures. These shields may be of several types, from the simple Whipple shield – a thin "bumper" layer of metal placed at a standoff distance from a thicker back wall (a pressure vessel or component wall), to more sophisticated multi-shock blankets. Debris objects large enough to be tracked by radar (~10 cm or larger) can be avoided by propulsive maneuvers.

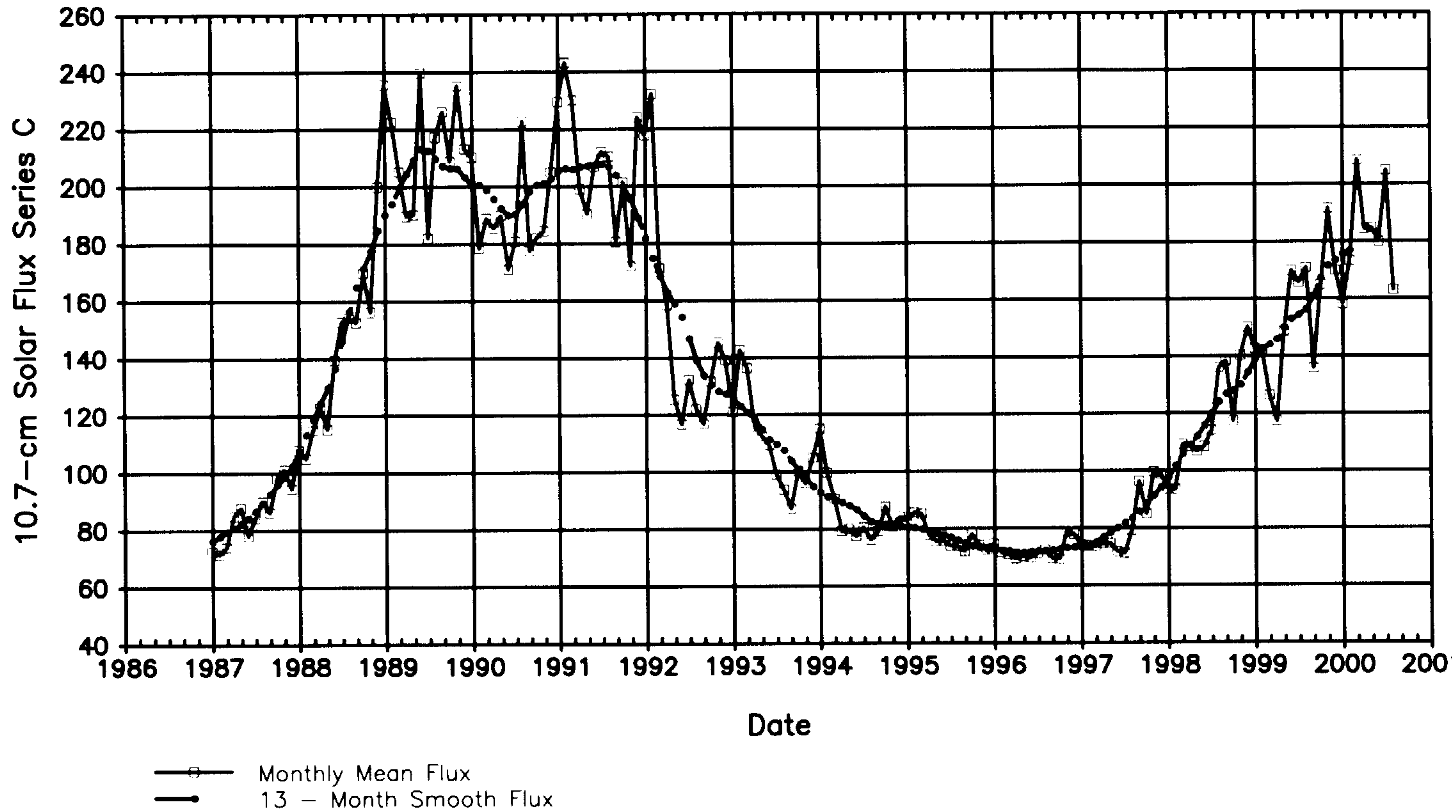
Ionizing radiation experienced in LEO has several components: geomagnetically trapped protons and electrons (Van Allen belts); energetic solar particles; galactic cosmic rays; and albedo neutrons. These particles can have several types of prompt harmful effects on equipment and crew, from single-event upsets, latchup, and burnout of electronics, to lethal doses to crew. Ionizing radiation is an omnipresent, omnidirectional threat, but exposures to these types of radiation will be increased through repeated passage of the spacecraft through the South Atlantic Anomaly (a region where the trapped radiation approaches the Earth's surface more closely than elsewhere), or by solar eruptive events such as flares and coronal mass ejections (CME's). Individual flares and CME's are unpredictable, but their frequency increases during times of maximum solar activity. Countermeasures to ionizing radiation consist of providing sufficient shielding mass to attenuate the flux to sensitive components and personnel; building electronics and other equipment that has an inherently low vulnerability to radiation damage (hardening); and limiting the exposure time of crew members.

All three types of prompt threat show some dependence on the solar activity cycle. Atmospheric drag mitigation and large debris avoidance require propulsive maneuvers. M/OD and ionizing radiation require some form of shielding for crew and sensitive equipment. Limiting exposure time is a mitigation technique for ionizing radiation and meteor streams.

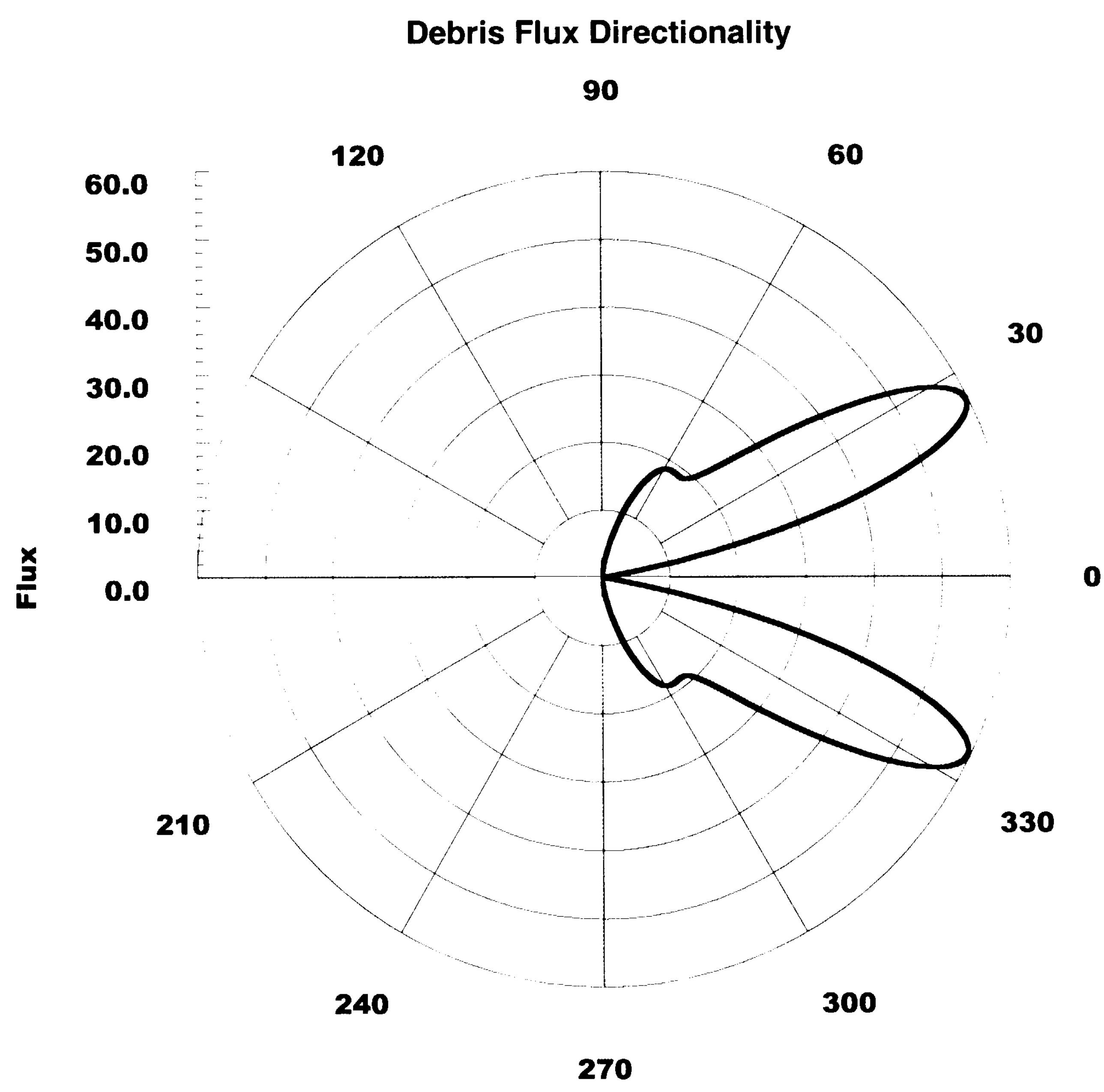
[1] H. Euler and S. Smith, "Future Solar Activity Estimates for Use in Prediction of Space Environmental Effects on Spacecraft," September 2000, http://sail.msfc.nasa.gov/nse/solar.html .

Figure 1. Monthly Mean and 13-Month Smoothed solar flux at 10.7 cm since 1987.

Figure 2. Orbital debris directionality: case at 51.6 degrees inclination and 400 km altitude. Zero degrees marks the satellite velocity direction.



10.7–cm Solar Flux Series C
260
240
220
200
180
160
140
120
100
80
60
40
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Date
Monthly Mean Flux
13 – Month Smooth Flux


Debris Flux Directionality
90
120
60
30
0
330
300
270
240
210
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Flux