JOURNAL OF SPACECRAFT AND ROCKETS
Vol. 32, No. 1, January–February 1995

Engineering Notes

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Active Control of Containment Particulates in a Low-Earth-Orbit Near-Spacecraft Environment

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I. Introduction

PARTICULATE contamination may enter the spacecraft environment through active release of particles from the spacecraft. Sources of these particles include dust collected on the ground and shaken loose during spacecraft operations; micron-size particulates broken off due to forces associated with solar illumination, thermal stresses due to terminator crossing, or electrostatic repulsion induced by differential charging in the ambient plasma; and particles created by firing of rocket motors and effluent dumps. These particles may interfere substantially with electromagnetic observations in the infrared, visible, and ultraviolet regions of the spectrum. (For example, such problems resulted in periodic loss of the star-tracker lock on the Magellan and Mars Observer[1] missions.) More generally, calculations show that remote observations will be affected by micron-class particles due to solar illumination, earth radiation, and particulate self-emission.[2] Currently the deleterious spacecraft environmental interactions are handled by design or by passive control methods that do not require specific action at the time of contaminant presence (e.g., baffles, removal of spurious signals within software), neither of which result in complete removal of the contaminating signals. In the next generation of spacecraft it will be possible to control some of the interactions actively, due to growth in the capability to sense and locally compute the environment with very fast microprocessors. The major benefit of active control of any design-limiting problem is that it opens up whole new regions of design space for a spacecraft designer to explore. This work involves examination of the effectiveness of three possible active methods to clear and control micron-class contaminant particles. The first is the firing of cold gas jets to remove particles from the view angle of a sensor. The second is to modify the electric field surrounding the spacecraft so that the particles are repelled from the sensor. The third is to use electron beams to increase particulate charge so that ambient electromagnetic forces will have a greater effect.

II. Methodology

This study uses 2-D and 3-D simulations to examine the contamination effects from dust particles in the near field of a low-earth-orbit (LEO) spacecraft. The contaminant effects are viewed from the perspective of an electromagnetic sensor located on the front of the spacecraft, with a view angle taken to be a cylinder extending forward for 1 km. The three different active control methods described above are examined with respect to this system. The 2-D spacecraft is modeled as shown in Fig. 1, and the 3-D one is modeled as a cylinder such that a cross-sectional cut through the equatorial plane yields the 2-D model. Spherical micron-class quartz particles, such as may be found in beta cloth, are assumed to be released impulsively from the surface due to some shock to the spacecraft (e.g., the dislodging of particles due to firing of a thruster) with a maximum release velocity of 5 m/s in a cosine distribution pattern. For simplicity, the shock is assumed to operate uniformly across the entire region, as shown in Fig. 1, releasing all particles at the same point in time. The number of particles released was 10,000 for the 2-D case and 25,000 for the 3-D case. These numbers have no absolute meaning but were sufficient to reduce time-dependent fluctuations in the results.

Once the particles are released, the forces on them and the charges on their surfaces are calculated self-consistently. Particle charge calculations assume orbit-limited currents and neglect the comparatively small photoelectric current and secondary yield. Significant forces considered include the electrical force due to the spacecraft surface potential, the Lorentz force due to the earth's magnetic field, the drag due to the neutral wind of the orbit, solar pressure, and any force induced by an active control method in use. In Fig. 2, forces acting on a sample 5-μ particle are plotted against altitude. Simple characteristic locations near the spacecraft are examined for location-dependent forces. The particle charge was taken to be steady state. The neutral drag is clearly the dominant force up to 400 km. At that point, the force due to the spacecraft electric field is higher, but only at the wall, and it falls off quickly. Solar pressure is comparable to neutral drag at approximately 600 km.

The active control methods examined are based on gasdynamic and electrodynamic forces. The gasdynamic drag force can be altered by the emission of gas from nozzles on the spacecraft surface. Two ways to affect the electrodynamic drag force are to project an electric field from the spacecraft to repel the negatively charged particles (negative because the particles will preferentially collect electrons), or to increase the negative charge of the particles (using an electron beam to deposit transient charge) so that the particles are caught in the earth's magnetic field and are swept out of the spacecraft environment.

In two dimensions two N_2-fueled cold gas jets are symmetrically located on either side of the sensor, angled outward to propel particles away from the sensor. Compensational thrusters are assumed to be located in the rear of the spacecraft. In three dimensions more thrusters are included. The analytical model used to determine the density of the gas from these jets is a continuum far-field model from a plume survey article by Dettleff.[3] The model is not accurate in the near field, and so the simulation limits the density not to exceed the exit density. Due to the continuum nature of this model, the effect at large angles is underestimated, so this represents a lower bound on the effectiveness of the jets. In the simulations, jets are fired at 10 mN for single-second bursts at a variety of angles with respect to the spacecraft velocity vector.

The electric field around the spacecraft is modified by negatively biased wires protruding out from the spacecraft (-1000 V for these simulations) and placed around the sensor. In using the electron beam, it is assumed to deposit the maximum possible charge on the particle without causing the surface electric field to exceed the

Received March 4, 1993; revision received March 7, 1994; accepted for publication March 8, 1994.

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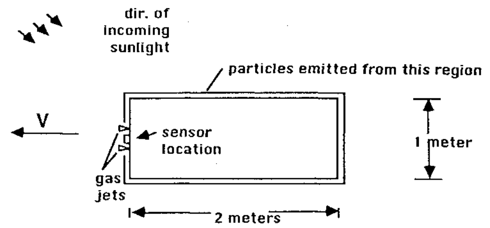

Fig. 1 Spacecraft model.

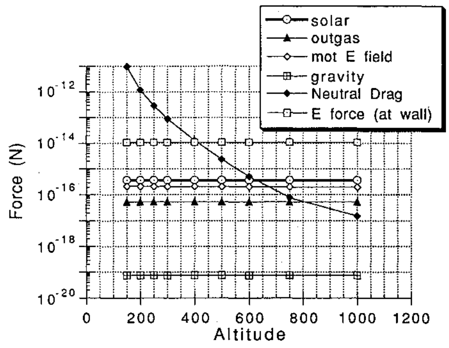

Fig. 2 Force on a 5-μ particle vs altitude (km).

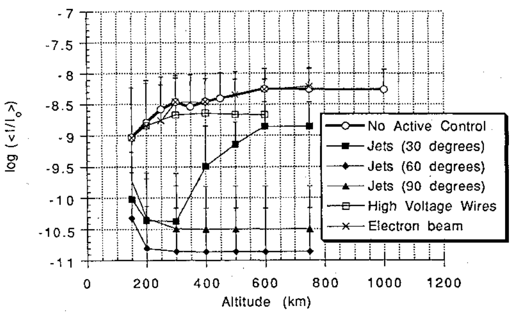

Fig. 3 Intensity plot (2-D) comparing all control methods.

dielectric breakdown strength. This is done to get an upper bound on the effectiveness of this method. In both cases, the spacecraft surface potential is assumed to be maintained by a plasma contactor in the back of the spacecraft.

III. Results

Simulations were performed for two and three dimensions, and over a range of equatorial LEOs with altitudes from 150 to 1000 km. The quantity of interest from the viewpoint of the sensor is the noise or scattered signal associated with the presence of the particles. The intensity of the scattered sunlight from the particles is determined using Mie scattering theory for particles much larger than the wavelength, so that the calculation is valid for visible light and for short-wavelength infrared radiation.[4] The scattered intensity normalized by the intensity of the incident radiation is proportional to the square of the ratio of particle radius to particle distance from the sensor. The total scattered intensity is determined as the sum of the scattered intensities of the particles.

For each altitude, the normalized scattered intensity is averaged over the first 10 s of each simulation. These intensity averages are shown in Fig. 3 (2-D case) and in Fig. 4 (3-D case). The error bars included in the plots indicate the standard deviation of the intensity average for each point.

The gasdynamic forces are seen clearly to be the superior method of affecting the particles. In the 2-D case, there is improvement of one to three orders of magnitude in the average normalized scattered intensity. The 3-D improvements are far less dramatic, due to the fact that the particles may travel between gas jets to reach the sensor view, thus avoiding the strongest areas of control. Four additional

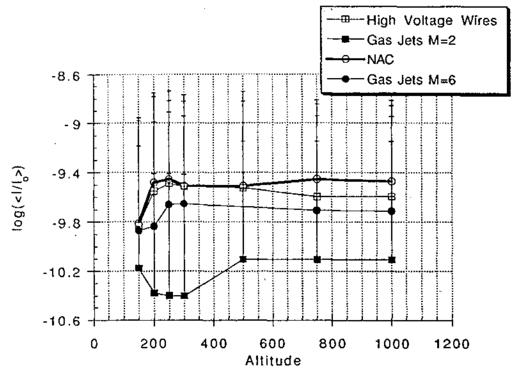

Fig. 4 Intensity plot (3-D) comparing effectiveness of control methods.

gas jets were added in this case, but that was insufficient to yield comparable results to the 2-D case. This implies that they would be quite effective if particulates are generated from a specific location on the spacecraft.

In general it is observed to be the case that for this range of particle sizes, the control methods that rely on electromagnetic forces are significantly less effective than the gasdynamic ones. If the particles of concern, however, had a higher charge/mass ratio, electromagnetic methods would have been more effective than they were here.

Acknowledgment

This work was supported by funds from The Johns Hopkins University Applied Physics Laboratory.

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Laser Velocimetry Seed-Particle Behavior in Shear Layers at Mach 12

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Introduction

ALTHOUGH laser velocimetry (LV) methods have been employed since the 1960s, the LV data base for hypersonic flows is extremely limited. That is primarily because frequency-domain and counter processors with the ability to efficiently examine the high-frequency signal bursts associated with hypersonic particles have only recently become available. Another factor contributing to the lack of hypersonic data is poor seed particle response characteristics. The considerable momentum possessed by particles at hypersonic velocities prevents them from accurately tracking the fluid streamlines. Because LV systems measure the velocity of the

Received Feb. 18, 1994; revision received Oct. 17, 1994; accepted for publication Oct. 28, 1994. This paper is declared a work of the U.S. Government and is not subject to copyright protection in the United States.

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