

Comparison of Reduced Order Spacecraft Charging Models for Electrostatic Proximity Operations

Julian Hammerl
Graduate Research Assistant
Aerospace Engineering Sciences
University of Colorado Boulder
Boulder, Colorado 80303
julian.hammerl@colorado.edu

Kaylee Champion
Graduate Research Assistant
Aerospace Engineering Sciences
University of Colorado Boulder
Boulder, Colorado 80303

Hanspeter Schaub
Professor and Department Chair
Schaden Leadership Chair
Aerospace Engineering Sciences
University of Colorado Boulder
Boulder, Colorado 80303

Abstract—Spacecraft charge in orbit due to naturally occurring electric currents from the ambient plasma and the Sun, and artificial currents produced by devices such as an electron gun. This results in electrostatic forces and torques between two spacecraft in close proximity that can perturb the relative motion during on-orbit servicing, assembly and manufacturing (OSAM) operations, or be utilized to remove or detumble dysfunctional satellites. In prior work on electrostatic proximity operations, typically charging models based on spherical current collection were used to compute the electrostatic potential, and that potential was prescribed to be constant in relative motion simulations. In this work, several spacecraft charging models are compared, including a simple sphere model, an adjusted sphere model, and a faceted model. The faceted model is promising because its total surface area is more accurate, and it allows for the consideration of a time-varying sunlit area. Using the faceted model, it is shown that the orientation of the spacecraft with respect to the sun can significantly affect the equilibrium potential and the resulting force and torque. This is demonstrated by a charged attitude motion simulation for the Electrostatic Tractor debris removal concept.

1. INTRODUCTION

Spacecraft naturally build up electric potentials in orbit due to several electric currents in the space environment, such as the photoelectric current from the Sun or the electron and ion current from the ambient plasma [1, Chapter 1]. Spacecraft charging is usually not a concern in Low Earth Orbit (LEO) due to the dense and low-energy plasma, with the exception of a few distinct scenarios such as when a spacecraft is located at auroral latitudes during auroral activities. In high earth orbit, such as the Geostationary Earth Orbit (GEO) or cislunar space the plasma is tenuous and energetic, resulting in high electric potentials reaching tens of kilovolts in eclipse. Record charging events of up to -19 kV were experienced by the Applied Technology Satellite 6 (ATS-6) in GEO [2].

Spacecraft charging affects spaceflight in various ways. Even though modern spacecraft design guidelines recommend to connect all components to one common ground such that all components charge to the same potential [3, Chapter 3], this is not always possible and often not the case for old or retired satellites. Arcing can occur between two components of a satellite if they are charged to different potentials, which potentially reduces the lifetime of solar panels, for example [4, 5]. Electrostatic discharges can occur between two charged spacecraft during docking if the difference in electric potentials is large. One consequence of spacecraft charging that has received increased attention over the last decade are the electrostatic forces that act on two charged space-

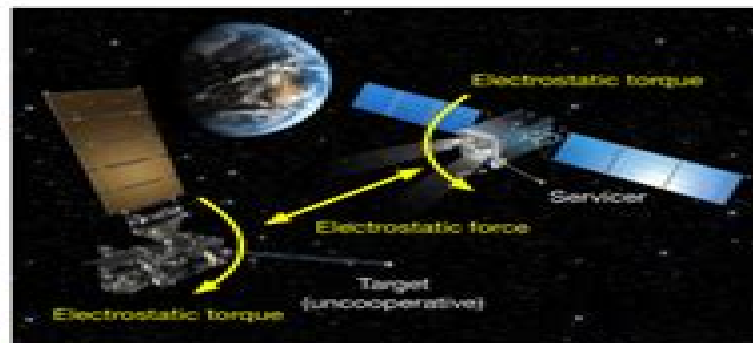


Figure 1. Concept Figure of electrostatic forces and torques

craft in close proximity operations (Fig. 1). Electrostatic perturbations can significantly influence On-Orbit Servicing, Assembly and Manufacturing (OSAM) operations [6]. When an uncooperative target satellite is approached by a servicing satellite, the target starts to tumble due to the electrostatic torques if its center of mass is not aligned with its center of charge. The servicer needs to match this rotation to maintain a constant relative orientation with the target during rendezvous and docking. This increases fuel consumption and complicates servicing operations. The electrostatic forces and torques can also be utilized to remove space debris from geostationary orbit with the Electrostatic Tractor (ET) active debris removal method [7], or to detumble uncooperative spacecraft [8].

Prior work on the effects of electrostatic perturbations on proximity operations investigated adjusted approach trajectories that minimize the electrostatic torques and the resulting rotational rate of the target satellite. A relative motion controller that feeds forward on the expected electrostatic perturbations to improve rendezvous performance was also studied [9]. However, all prior work prescribed electric potentials of 10 kV for each spacecraft assuming extreme charging scenarios, without considering the interactions of the spacecraft with the plasma environment. Time varying potentials about the nominal potential of 10 kV were taken into account by introducing random variation, but this does not accurately represent the changing space environment around the Earth

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