Available online at www.sciencedirect.com

ScienceDirect

Advances in Space Research 53 (2014) 110–118

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

www.elsevier.com/locate/asr

# Active space debris charging for contactless electrostatic disposal maneuvers

Hanspeter Schaub [a,*,1], Zoltán Sternovsky [b]

[a] Aerospace Engineering Sciences Department, University of Colorado, Boulder, CO 80309, United States

[b] Laboratory for Atmospheric and Space Physics, Aerospace Engineering Sciences Department, University of Colorado, Boulder, CO 80303, United States

Received 21 May 2013; received in revised form 2 October 2013; accepted 7 October 2013
Available online 14 October 2013

**Abstract**

The remote charging of a passive object using an electron beam enables touchless re-orbiting of large space debris from geosynchronous orbit (GEO) using electrostatic forces. The advantage of this method is that it can operate with a separation distance of multiple craft radii, thus reducing the risk of collision. The charging of the tug–debris system to high potentials is achieved by active charge transfer using a directed electron beam. Optimal potential distributions using isolated- and coupled-sphere models are discussed. A simple charging model takes into account the primary electron beam current, ultra-violet radiation induced photoelectron emission, collection of plasma particles, secondary electron emission and the recapture of emitted particles. The results show that through active charging in a GEO space environment high potentials can be both achieved and maintained with about a 75% transfer efficiency. Further, the maximum electrostatic tractor force is shown to be insensitive to beam current levels. This latter later result is important when considering debris with unknown properties.



*Keywords:* Space debris; Electrostatic tractor; Electron beam

## 1. Introduction

The threat of space debris on satellite operations has increased to the point where avoiding creating debris is no longer sufficient (Johnson, 2010). The tipping point has been reached where the low-Earth orbit space debris population will continue to increase even if no additional satellites are launched, due to debris–debris collisions (Liou, 2011). While having less debris than the Low Earth Orbit (LEO) regions, the Geostationary Earth Orbit (GEO) region is a very narrow zone with a growing number of large, defunct Earth sensing and communication satellites, as well as spent rocket bodies. Of the over 1200 large GEO object tracked, less than 400 are controlled, functioning satellites (Jehn et al., 2005). The GEO satellites are high-value spacecraft, and the GEO space debris concern is a growing concern with operators and associate insurance agencies (Chrystal et al., 2011). International guidelines specify that GEO spacecraft must move to a disposal orbit at their end of life. However, this is not done by all operators, or technical failures prevent this final step. Thus, active debris removal at GEO is a critical capability to avoid frequent debris avoidance maneuvers (Anderson and Schaub, 2013).

Active debris removal (ADR) remains a challenging discipline with no solutions operating in space (Richards et al., 2005). Envisioned concepts range from robotic docking (Smith et al., 2004; Bosse et al., 2004), electrodynamics tethers for LEO applications (Pearson et al., 2003), electric sails(Janhunen et al., 2013), as well as space debris pushers using contactless directed ion exhaust plumes (Bombardelli and Pelaez, 2011; Bombardelli et al., 2011; Kitamura, 2010). Schaub and Moorer (2010) discuss a novel, patented

* Corresponding author. Tel.: +1 3034922767.
*E-mail addresses:* hanspeter.schaub@colorado.edu (H. Schaub), zoltan.sternovsky@lasp.colorado.edu (Z. Sternovsky).

[1] H. Joseph Smead Fellow.

0273-1177/$36.00 
http://dx.doi.org/10.1016/j.asr.2013.10.003

approach to moving large, tumbling GEO debris to disposal orbits 250–300 km above the geosynchronous zone as illustrated in Fig. 1. Here the tug employs continuous electron emission to raise its own potential to a positive value of 10s of kilo-volts, while the electron emission is directed at the space debris object to yield a negative potential. Simultaneously low-thrust inertial thrusters are employed on the tug to raise the two-vehicle system altitude (Moorer and Schaub, 2011b,a). Thrusters must be selected whose exhaust plume does not impinge on the charged neighboring space object. Neutral gas thrusters could be used, as the $\Delta v$ requirement to move a debris object to the disposal orbit is only about 11 m/s. The resulting attractive inter-vehicle force is referred to as the electrostatic tractor (ET) and will reach magnitudes of several milli-Newtons assuming a separation distance of 15–25 m. Even large multi-ton debris objects can be moved or reorbited to a disposal orbit in 2–4 months (Schaub and Jasper, 2011). The pulling configuration with attractive electrostatic forces is preferred due to (a) increased forces for a given potential, (b) passively stable relative orientation, as well as (c) superior failure modes having the tug pull away safely if the ET fails (Schaub and Jasper, 2013).

The focus of this paper is the charge transfer process itself for this ET concept. Established fundamental plasma physics and charging models are applied to the ET concept to evaluate ideal potential distributions between the tug and debris, as well as approximated expected charge transfer efficiencies. To obtain analytical approximations of the expected ET force, the spacecraft are assumed to be spherical. Jasper and Schaub (2012) discuss why this is a reasonable assumption, even with large GEO communication satellite shapes, if the separations are 2–3 craft radii.

Active charge control for space-based actuation is first discussed by Cover et al. (1966), were the GEO region is

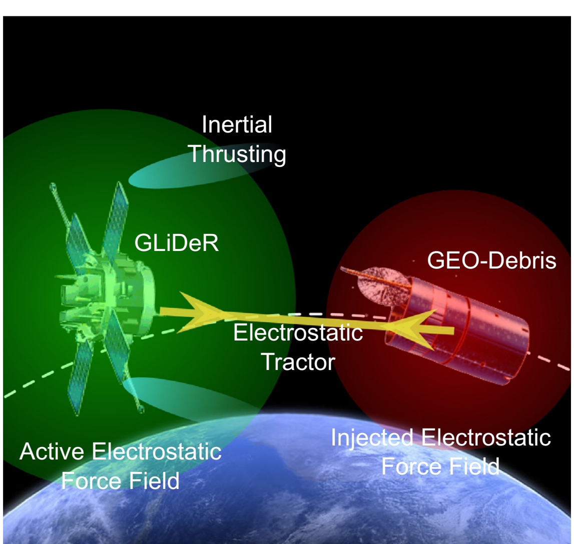


Fig. 1. Illustration of the geosynchronous large debris reorbiter (GLiDeR™) concept.

identified as ideal for active charging applications where kilo-volts of potential can be achieved using as little as watt-levels of electrical power. Cover discusses using these forces for electrostatic membrane inflation. King et al. (2003) discusses active charge control to directly control relative motion of spacecraft having identified that the naturally occurring space weather related charging observed on the SCATHA (Mullen et al., 1986) and ATS missions could lead to significant disturbance forces on nearby space objects. This has led to extensive research studying charged relative motion dynamics for cluster and formation flying (Natarajan and Schaub, 2008; Wang and Schaub, 2011). Recently, the use of hybrid actuation (employing both electrostatic forces and inertial thrusters) to control the relative motion while performing inertial orbit corrections is discussed by Hogan and Schaub (2013). This work identifies the importance of ET effectiveness bounds in the relative motion stability analysis. The ET concept is also discussed by Murdoch et al. (2008) for asteroid deflection applications. This work illustrates that with large space object potentials relative to the plasma energies, the Debye length related shielding of electrical charges is reduced. For the GEO debris application the average minimal Debye lengths are on the order of 180–200 m (Denton et al., 2005), making Debye shielding concerns minimal for the ET operation.

The ET concept is also of interest for on-orbit servicing of satellites to enable novel relative motion control with the to-be-serviced satellite, including touchless repositioning as discussed by Hogan and Schaub (2012). The servicing missions considered may include refueling, part replacement or repair and forced orbit change. There are a number of envisioned concepts, including using (a) robotic arms for docking and deployment of de-orbiting devices (Bosse et al., 2004; Castronuovo, 2011; Xu et al., 2011), or (b) non-robotic capture with nets, tethers or inflatable devices (Pearson et al., 2003; Kawamoto et al., 2006).

The prior Coulomb actuation studies do not consider the electron charge transfer process between two space objects. The active charge emission is performed on each space object individually, and is assumed to not impact the charging of a neighboring object. This paper performs an analytical study of how well the ET concept will operate taking into account the diverse spacecraft charging effects due the plasma space environment, photo-electron current, secondary electron emission, as well as the charge imparted by the space tug. The charge transport onto space particles is studied by the dusty plasma community (Sternovsky et al., 2001; Žilavý et al., 1998). Plasma analysis tools are employed to study the ET effectiveness for GEO debris actuation. Of interest are what ideal tug and debris potentials yield the best ET magnitude given the limited charge emission energies, the effectiveness of the charge transfer process for a range of tug potentials, as well as the sensitivity of the ET performance on tug potential uncertainties.

The article is organized as follows. In Section 2 the main forces acting on the tug–debris system are discussed. Of