P09

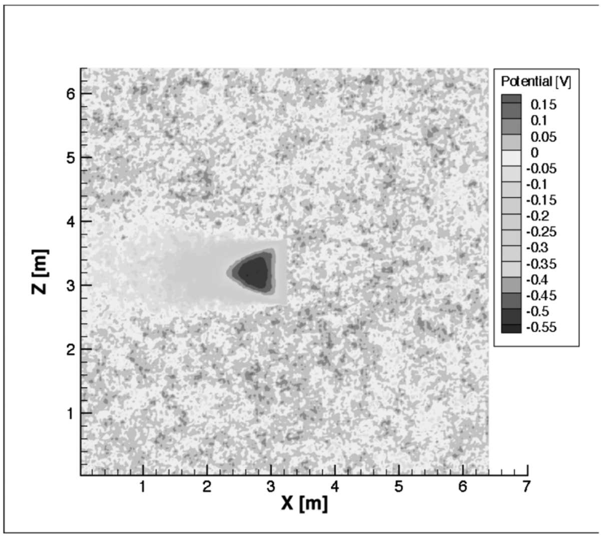
帯電薄膜を利用した抗力増大装置による大型デブリの軌道遷移技術の開発

Orbit Transition of Large-scale Debris Using Drag Force Intensifier Applying Charged Membrane

村中崇信，永田拓雅，長原拓哉，永井宏樹（中京大）
Takanobu Muranaka, Takuma Nagata, Takuya Nagahara and Hiroki Nagai (Chukyo Univ.)

本研究では，帯電薄膜を利用した抗力増大装置によるデブリの軌道遷移技術を開発し，地表高度 800km から 1000km の混雑軌道における大型デブリ除去実証に適用することを目指している．その原理は，電離層に存在する希薄大気の抗力を利用するもので，地表高度 400km から 600km 程度の低軌道衛星軌道遷移に利用される原理と等しい．大気の効力は動圧に比例するが，除去対象の大型デブリが存在する高度1000kmの大気密度は 600km および 400km のそれらと比較して，それぞれ 1/50 および 1/100 であり，抗力もそれぞれ 1/50 および 1/100 程度である．そこで本研究では，1m 四方から 3m 四方程度の薄膜を抗力発生装置とし，これを帯電させることで高層待機中に多く存在するイオンによる効力を増大し，地表高度 600km 程度の大気抵抗と同等の効力を発生させる衛星コンポーネントの開発を目指す．ここでは，本システムの基本原理と，電離層プラズマ中におけるイオンによる効力発生の基礎となる，薄膜電位周辺の電位構造と薄膜が収集するイオン電流について，数値シミュレーションによる解析結果を紹介する．

Expansion of space utilization activities increases the number of large-scale debris like an upper stage of the launch vehicle in congested orbit at altitude of 800-1000 km. These debris collide with others producing a lot of smaller debris that would cause further collisions to spacecrafts and their destruction in orbit. For these reasons, some low-cost debris removal systems are proposed, and a part of fundamental technologies had already been demonstrated by space agencies in space. The atmosphere at the altitude of 800-1000 km is composed of neutral particles of He, H, O and ions of O+, H+. One of the conventional de-orbit system uses a deployable sail capturing the neutral particles to produce a drag force which had already been demonstrated on-orbit at the altitude of 400 to 600 km. The drag force decreases orbital velocity of a spacecraft and then the spacecraft will move to the lower orbit to the earth. This type of de-orbit system is very simple, but a large-scale structure is necessary to produce enough drag force for a large-scale debris. In this research, we focus on the ions existing in the atmosphere at high altitude to enhance the drag force for the removal system. The concept of de-orbit system utilize an ion sheath generated by a charged deployable thin film whose scale is considered to be 1 m×1 m to 3 m×3 m. In this paper, as a preliminary study, we introduce the fundamentals of the debris removal system using the charged membrane. The performance of the system is also discussed as the variations of the atmospheric environment in LEO, and the potential structure around the charged membrane is analyzed by a 3D full particle electrostatic code to determine a proper method to bias the membrane.



Orbit Transition of Large-scale Debris Using Drag Force Intensifier Applying Charged Membrane

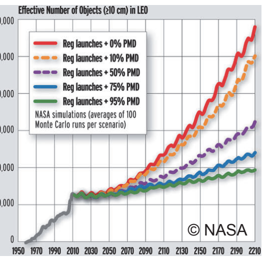
○Takanobu Muranaka[1], Takuma Nagata[1], Takuya Nagahara[1], and Hiroki Nagai[1]

[1]Chukyo University, Japan

abstract: We propose a low-cost and sustainable debris removal system using a charged membrane to utilize the ions in the congestion orbit as well as the neutral particles at altitude of 800-1000 km. The atmosphere at the altitude is composed of neutral particles of He, H, O and ions of O^+, H^+, so the membrane can produce atmospheric drag to decelerate the orbital motion and then the debris will move to the lower orbit to the earth. The concept of the system utilize an ion sheath generated by a charged deployable membrane whose scale is considered to be 1 m×1 m to 3 m×3 m. The charged membrane accelerates the incoming ions onto it by electrostatic force multiplying the momentum transfer to the membrane. In this paper, as a preliminary study, we introduce the fundamentals of the debris removal system using the charged membrane. The performance of the system is also discussed by 1D theoretical estimation in actual space environment, and the potential structure around the charged membrane is analyzed by a 3D full particle electrostatic code to determine a proper method to bias the membrane.

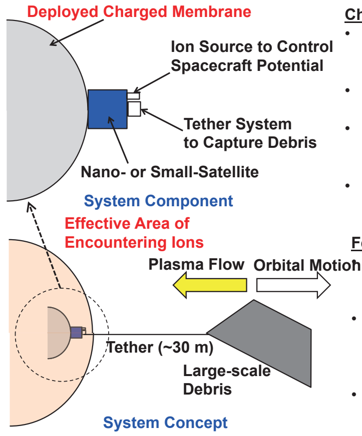
1. Background & Purpose of This Study

Expansion of space utilization activities increases the number of large-scale debris like an upper stage of the launch vehicle in congested orbit at altitude of 800-1000 km. These debris collide with others producing a lot of smaller debris that would cause further collisions to spacecraft and their destruction in orbit. For these reasons, some low-cost debris removal systems are proposed, and a part of fundamental technologies had already been demonstrated by space agencies.



One of the conventional deorbit system uses a deployable sail capturing the neutral particles to produce a drag force which had already been demonstrated on-orbit at the altitude of 400 to 600 km. The drag force decreases orbital velocity of a spacecraft and then the spacecraft will move to the lower orbit to the earth. This type of deorbit system is very simple, but a large-scale structure is necessary to produce enough drag force for a large-scale debris. The atmosphere at the altitude of 800-1000 km is composed of neutral particles of He, H, O and ions of O^+, H^+. In this research, we focus on the ions existing in the atmosphere at high altitude to enhance the drag force for the removal system. The concept of deorbit system utilize an ion sheath generated by a charged deployable membrane whose scale is considered to be 1 m×1 m to 3 m×3 m.

2. System Concept and Component



Charged Membrane:

- One of the components of the system (1m x 1m to 3m x 3m)
- Negatively charged up to -100V to attract ions
- Attracted ions enhance drag force on the membrane
- Both neutral particles and attracted ions contribute to generate drag force

Features:

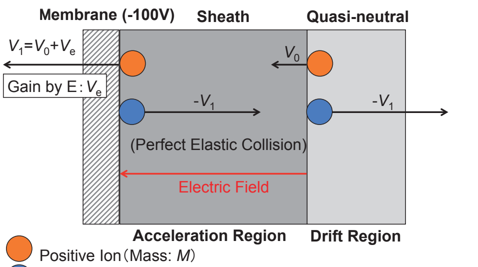
- Using tether (~30m) can avoid ion wake downstream debris
- Expanded sheath around negatively charged membrane can collect more ions
- Enhancement of "Drag" can be achieved by single ion acceleration & increase of the ion currents

Orbital Drag (Dynamic Pressure): Flux conservation / Gain by ion acceleration

$$P_D = \frac{1}{2} C_D \rho_{n0} v_D^2 + \frac{1}{2} C_D \rho_i v_i^2 \qquad \frac{1}{2} C_D \rho_i v_i^2 = \frac{1}{2} C_D \underline{(\rho_{i0} v_D)} (v_D + \underline{\sqrt{2 q_i \Phi_m / m_i}})$$

3. Drag Force by Charged Membrane

Mechanism of momentum transfer



Positive Ion (Mass: M)

Neutral Particle (Neutralized Ion by Coupling Free Electron, Mass: M)

Momentum Transferred to Membrane: $M(V_0-(-V_1))=2MV_0+MV_e$

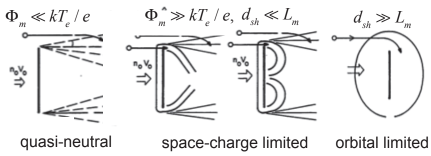
→Enhanced Momentum by E field → Enhancement of Drag Force

Neutral Particle does not feel E field

→Membrane does not lose obtained momentum

Increase of current collection of ions

Wang, J., PhD thesis, MIT (1999)



Space environment

2016/01/03 (perihelion) 13:00

Altitude [km]	Particle Density [m^{-3}] e	O^+	H^+	O	H	He
800	8.49E+10	6.98E+10	1.24E+10	1.38E+11	8.24E+10	5.79E+11
1000	4.01E+10	2.33E+10	1.49E+10	7.06E+09	6.84E+10	2.76E+11

Neutral atmosphere: *NRLMSISE-00*
Ion density: *IRI−2016*

Theoretical estimation (1D sheath)

2016/01/03 (perihelion) 13:00 at 800 km

Dynamic Pressure [Pa]	Membrane Potential [V] 0	-50	-100
Neutral Particle, Pn	4.25E-08	4.25E-08	4.25E-08
Ion, Pi (Pi/Pi at 0V)	1.74E-08 (1.00)	8.21E-08 (4.73)	1.09E-07 (6.27)
Total, Pt (Pt/Pt at 0V)	5.99E-08 (1.00)	1.25E-07 (2.08)	1.51E-07 (3.05)

2016/01/03 (perihelion) 13:00 at 1,000 km

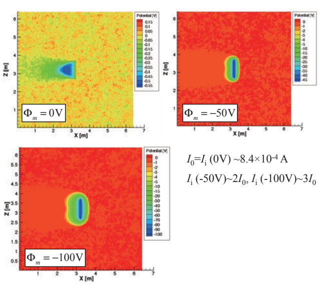
Dynamic Pressure [Pa]	Membrane Potential [V] 0	-50	-100
Neutral Particle, Pn	1.07E-07	1.07E-07	1.07E-07
Ion, Pi (Pi/Pi at 0V)	3.92E-08 (1.00)	1.75E-07 (4.46)	2.31E-07 (5.90)
Total, Pt (Pt/Pt at 0V)	1.47E-07 (1.00)	2.82E-07 (1.92)	3.38E-07 (2.31)

Numerical Simulation

3D full-PIC simulation:
Compute potential structure around membrane and current collection on the surface

Membrane size	1 m × 1 m × 0.05 m
Calculation system	6.4 m × 6.4 m × 6.4 m
Orbital speed	7350 m/s
Ion (O^+)	
Density	7×10^{10} m^{-3}
Atomic mass	16 amu
Temperature	0.1 eV
Thermal speed	1097 m/s
Electron	
Density	7×10^{10} m^{-3}
Temperature	0.1 eV
Thermal speed	187,426 m/s

Preliminary results



$I_0=I_i$ (0V) ~8.4×10^{-4} A

I_i (-50V)~$2I_0$, I_i (-100V)~$3I_0$

conclusion:

- We propose a drag force intensifier using charged membrane for de-orbiting a large-scale debris
- The system utilizes ions in congestion orbit (altitude of 800 km to 1,000 km) as well as neutral particles
- 1D Theoretical estimation expects the total gain of the drag to be 3.05 and 2.31 at the potential of -100 V at 1,000 km, respectively
- To increase the current collection, expansion of the sheath is required applying larger magnitude of negative potential to membrane
- Modifying the method to apply the potential to the membrane to keep directivity of the ion flow not to lose the ion drag (on-going)

8th Space Debris Workshop, JAXA Chofu Aerospace Center, December 3–5, 2018