P06

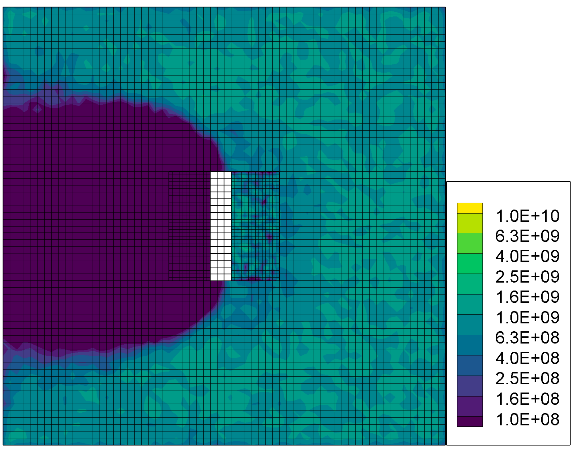
スペースデブリ除去装置への応用を目指した帯電薄膜による抗力増大装置の開発研究

Study on Drag Force Intensifier Applying Charged Membrane for Space Debris Removal

○村中 崇信（中京大学），奥村 哲平（JAXA），上野 一磨，
大塚 俊輔（中京大学），大川 恭志（JAXA）
○MURANAKA Takanobu (Chukyo Univ.), OKUMURA Teppei (JAXA), UENO Kazuma, OTSUKA Shunsuke (Chukyo Univ.), OHKAWA Yasushi (JAXA)

近年の宇宙活動の拡大に伴い，地球周回衛星の運用において，軌道上に存在するスペースデブリ（以後デブリ）が大きなリスクとなりつつある．そこで，これらデブリの数を低減する目的で，運用を終えた人工衛星が自ら軌道離脱し，地球大気圏に突入するPMD(Post Mission Disposal)のアイデアが検討されている．そのひとつに，宇宙機のミッション期間終了後に，軌道上で薄膜を展開し，薄膜に作用する高層大気の抗力を利用するデブリ除去装置が提案されている．本研究グループは，この薄膜を帯電薄膜とすることで高層大気中のイオンの抗力を増大させる新たなデブリ除去デバイスを考案し，実用化に向けた基礎研究を進めている．本発表では，この帯電薄膜デバイスの抗力増倍効果について述べ，抗力増倍に適した膜面への電圧印加手法について提言する．図はその一例として，数値計算によって得られた右から左に流れるイオンの数密度を示す．効果的膜面帯電により下流側へのイオンの回り込みが回避される様子を示す．

Increase of space debris has been becoming serious risk for spacecraft operation in near Earth orbit as space activities expand. To reduce the number of these space debris, methods for de-orbiting spacecraft by itself to the Earth after its lifetime are proposed. These methods are so called post mission disposal, PMD. A PMD device has successfully demonstrated in low Earth orbit (LEO) to produce atmospheric drag by using a deployable membrane. To enhance the drag for effective debris removal, we propose a new device composed of a charged membrane to utilize ions existing in the orbit. In this study, we present the magnification of the ion drag onto the charged membrane compared to that onto non-biased membrane, and also present appropriate method to bias the membrane to utilize the ion sheath to produce the ion drag. The figure shows a cross sectional view of the density of ions flowing right to left around charged membrane obtained by a numerical simulation. In the figure, an effective biassing method prevents turning of ions onto the downstream surface.



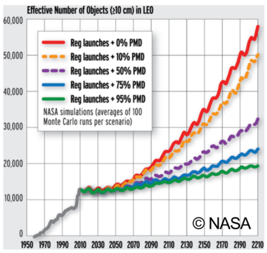
Study on Drag Force Intensifier Applying Charged Membrane for Space Debris Removal

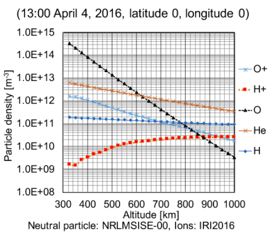
○Takanobu Muranaka[1], Teppei Okumura[2], Kazuma Ueno[1], Shunsuke Otsuka[1], Yasuhi Ohkawa[2]

[1]Chukyo University, Japan, [2]JAXA

Abstract: Increase of space debris has been becoming serious risk for spacecraft operation in near Earth orbit as space activities expand. To reduce the number of these space debris, methods for de-orbiting spacecraft by itself to the Earth after its lifetime are proposed. These methods are so called post mission disposal, PMD. A PMD device has successfully demonstrated in low Earth orbit (LEO) to produce atmospheric drag by using a deployable membrane. This device has the advantages of low-cost and simplicity of its component but disadvantage of uncontrollable drag. To improve the device, we propose a new device composed of a deployable charged membrane to utilize ions existing in the low earth orbit. In this study, we introduce the system concept and components, and present numerical analysis to determine appropriate biasing method on the surface of the membrane to utilize the ion sheath to increase the ion drag.

1. Background & Purpose of This Study

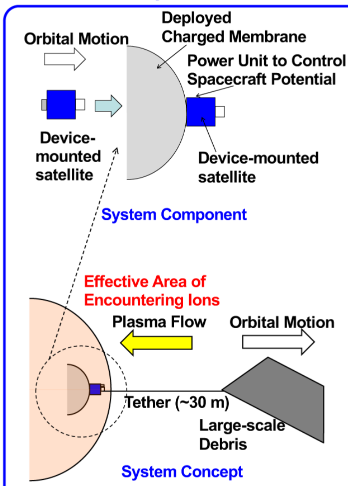




- Expansion of space utilization activities increases the number of space debris
- These debris collide with others producing a lot of smaller debris that would cause further collisions to spacecraft and their destruction in orbit (Kessler syndrome[1]).
- Removal of expecting debris (used satellite, parts of launch vehicles, etc.) is of importance to suppress increasing of debris (called Post Mission Disposal, PMD).
- One of a conventional PMD system uses a deployable membrane capturing the neutral particles to produce drag force, which had already been demonstrated on-orbit at the altitude of 400 km.
- This PMD system is very simple, but a large-scale structure is necessary to produce sufficient drag force for a large-scale debris.
- Using a charged membrane instead of the conventional one can utilize an ion sheath to attract orbital ions to generate more drag keeping the scale of the membrane.

[1] Kessler, D. J.: Collisional Cascading: The Limit of Population Growth in Low Earth Orbit, Advances in Space Research, 11, pp. 63–66, 1991

2. System Concept and Component



Charged Membrane:

- Major component of the system (1m x 1m to 3m x 3m)
- Negatively charged to attract ions by a mounted power unit
- Biasing method to utilize ion sheath should be considered
- Expanded sheath around negatively charged membrane can collect more ions

Features:

- Comparatively simple and low-cost
- Applicable as both PMD and ADR devices
- In use of ADR device, using tether (~30m) can avoid ion wake downstream debris
- Attracted ions onto the membrane enhance drag force
- Attracted ions as well as neutral particles contribute to generate drag force

3. Utilizing Ion Sheath by a Biassing Method on the Charged Membrane

Intensified Drag force

Drag force can be estimated as sum of the drag forces by neutral particle and ions

$$F_D = \frac{1}{2} C_D \rho_n v_D^2 A_m + \frac{1}{2} C_D \rho_i v_i^2 A_m^*$$

C_D: drag coefficient, ρ: density, v: velocity, A_m: area of membrane

Neutral drag: determined by orbital parameters

Ion drag:

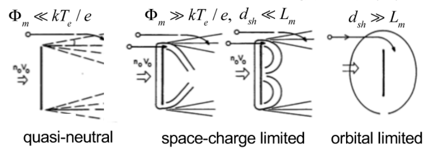
ρ_i, v_i: determined at the surface of membrane

A_m*: effective area of the membrane utilizing ion sheath

- Ion drag is intensified on the negatively charged membrane compared to that on non-biased membrane.
- Magnification of the ion drag can briefly be estimated by the magnification of the ion current onto the membrane

Expansion of Ion sheath

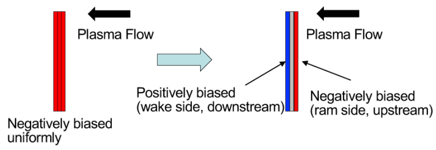
Wang, J., PhD thesis, MIT (1999)



$\Phi_m \ll kT_e/e$ $\quad$ $\Phi_m \gg kT_e/e,\ d_{sh} \ll L_m$ $\quad$ $d_{sh} \gg L_m$

- Ion sheath expands as absolute value of the negative potential on the membrane increases.
- Current collection of the ions onto the surface of the membrane can be controlled by the potential.

Effective Biasing Method on the membrane to Utilize Ion Sheath in LEO



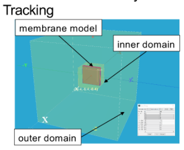
Biasing the ram (upstream) and wake (downstream) sides of the membrane separately can be effective to utilize ion sheath

- ram : negatively biased to attract ions
- wake : positively biased to repel ions

Numerical Analysis of Sheath and Current Collection in LEO

We performed numerical simulations To evaluate potential structure around the membrane, using MUSCAT2

- MUSCAT2: 3D multi-grid ES particle code
- Developed by JAXA
- Sheath is calculated by Particle-In-Cell, current collection by Particle Tracking

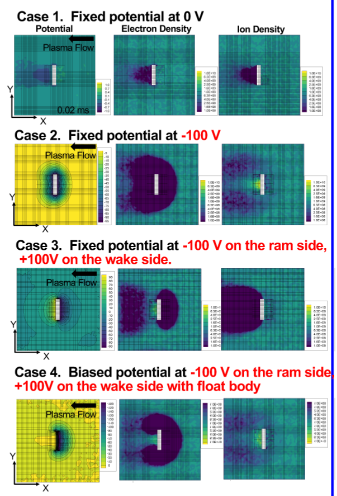


for these parameters, $\Phi_m/(kT_e/e) \gg 1,\ d_{sh}/L_t \sim 1$

dx/λ_D (inner)	0.77
dx/λ_D (outer)	1.5
dt (PIC)	$0.25\omega_{pe}$
λ_D/L_t	4.3×10^{-2}
$\lvert\Phi_m\rvert/(kT_e/e)$	333
ion	O^+
Mach No. (ion)	3.0

domain (inner)	3.2m × 3.2m × 3.2m
domain(outer)	6.4m × 6.4m × 6.4m
membrane	3.0m × 3.0m × 0.3m

Numerical Results



- In case 3, ions are almost repelled in the wake region of the membrane, that can be considered directivity of the drag is maintained
- In case 4, potentials of ram and wake side have changed to be -200V and 0V, respectively due to excess of electron current (Float potential is converged to be –100V), and characteristic potential structure around the membrane is shown

Conclusion:

- We propose a drag force intensifier using charged membrane for de-orbiting a large-scale debris
- The system is designed to apply ion drag as well as drag of neutral particles
- To enhance the ion drag, directivity of the ion current onto the membrane is controlled by a biassing method on the membrane: negative potential on the upstream surface, positive potential on the downstream surface.
- Effect of the biassing method to utilize the ion sheath for ion drag is analyzed by numerical simulations; the results show the biassing method is effective, the electrically floating potential will determine the magnitude of the potentials onto the surface of the membrane.
- Estimation of the magnification of the drag by ion drag is on-going by post processing of the numerical results.

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