Results from In-Orbit Electrodynamic Tether Experiment (KITE)

Yasushi Ohkawa, Teppei Okumura, Kentaro Iki, Hiroyuki Okamoto, Satomi Kawamoto and KITE-team (JAXA)

To demonstrate electrodynamic tether technologies for space debris removal, JAXA planned and conducted an in-orbit tether experiment called “KITE” on the H-II Transfer Vehicle 6 (HTV-6) in early 2017. Although the tether could not be deployed due to a mechanical malfunction of the end-mass releasing mechanism, other KITE devices such as a carbon-nanotube-based field-emission-cathode (FEC) and an electric potential monitor (LP-POM) operated well without any critical trouble. In the workshop, some examples of in-orbit data on the FEC and LP-POM and the current and future activities based on KITE technologies are to be presented.
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In-Orbit Electrodynamic Tether Experiment (KITE)

by
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Presentation Outline

- Electrodynamic Tether for Debris Deorbit, Pros and Cons
- KITE Objective and Mission Outline
- Results of KITE
- Current Activities
**Electrodynamic Tether (EDT)**

- EDT is “Propellant-free propulsion”

- Fundamentals
  - Attitude stabilization by gravity gradient
  - Self-induced electromotive force (EMF) by orbital motion
    - \( V_{emf} = (v \times B) \cdot L \)
  - Electron emission and collection
  - Electric current through tether
  - \( J \times B \) force for deorbit
    - \( F = (J \times B) \cdot L \)

**EDT for Debris Deorbit - Pros -**

- Deorbit propulsion is important for ADR

- Pros of EDT;
  - Propellant-free
  - Less electrical power required
  - No thrust vectoring required
  - No center-of-mass consideration required on attaching
  - No strong force required on attaching

- ADR system can be simpler and cheaper using EDT for deorbit
**EDT for Debris Deorbit - Cons and Countermeasures**

- Possibility of mission failure due to tether being severed
  - Tether severed by impacts of small debris or micrometeoroids
    ⇒ Reducing risk by adopting "net-type" tether

- Collision risk with operational satellites
  - Collision may cause damage on operational satellites
    ⇒ Risk should be assessed against mission payoff in advance
    ⇒ Collision avoidance maneuver by thruster or on/off of tether current
    ⇒ "Converging" tether

- Difficulty of controlled reentry
  - Controlled reentry is difficult because of low thrust levels
    ⇒ Target selection considering a hazard to the ground
    ⇒ Reentry control using chemical propulsion at final stage

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**Deorbit Capability of EDT (an example)**

- 10-km-EDT can deorbit 3.4-ton SSO debris from 800-km-altitude to atmosphere within a year

![Graph showing deorbit trajectory with and without control](image)
KITE - In-Orbit Demonstration of EDT -

Objective: To demonstrate key technologies of EDT preparing for future ADR

KITE Specifications (Planned)

<table>
<thead>
<tr>
<th>Platform</th>
<th>H-II Transfer Vehicle 6 (HTV-6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission period</td>
<td>7 days</td>
</tr>
<tr>
<td>Orbit</td>
<td>20 km (or more) below ISS orbit</td>
</tr>
<tr>
<td>Altitude</td>
<td>300 – 400 km</td>
</tr>
<tr>
<td>Inclination</td>
<td>52 deg.</td>
</tr>
<tr>
<td>Tether length</td>
<td>700 m (approx.)</td>
</tr>
<tr>
<td>Tether current</td>
<td>10 mA (approx.)</td>
</tr>
<tr>
<td>Electron collector</td>
<td>Bare tether</td>
</tr>
<tr>
<td>Electron emitter</td>
<td>Field emission cathode</td>
</tr>
</tbody>
</table>

※ Expected thrust: ~0.1 mN

KITE Components
Planned Mission Outline of KITE

- (1) Deployment of bare tether
- (2) Motion monitoring of tether and end-mass
- (3) Electrical potential generation by self-induced electromotive force
- (4) Electron collection by bare tether
- (5) Electron emission by field emission cathode (FEC)
- (6) Thrust estimation

Results of KITE - Summary -

- KITE mission began on January 28, 2017

- End-mass could not be released due to malfunction of its holding & releasing mechanism, so, tether deployment was unsuccessful

- Mission conducted through January 28 to February 4

- Field emission cathode (FEC), Plasma potential monitor (LP-POM) and other components operated well throughout mission period and many meaningful data were obtained
Malfunction of End-mass Holding & Releasing Mechanism

- At the first step of KITE, command for releasing end-mass was executed, but release was not detected.
- Although various attempts were performed throughout mission period, end-mass could not be released finally.
- Investigation team concluded that one of four separation volts, which fix end-mass to HTV body, was not separated due to inappropriate design.

Successful Operation of Carbon-Nanotube Based FEC

- Schematic of CNT-FEC
- FEC Module
- FEC-Head
**Successful Operation of Carbon-Nanotube Based FEC**

- Highest electron emission current by FEC ever demonstrated in space (5.8 mA)
- FEC showed decent tolerance to atomic oxygen in LEO
- HTV potential changed by active electron emission

![Graph showing I-V Characteristics during KITE](image1)

![Graph showing HTV Potential change by active electron emission](image2)

**Successful Operation of LP-POM**

- Electrical potential difference between HVT body and ambient plasma was measured by Potential Monitor (called LP-POM)
- Two potential sensors
  - TREK-3G Probe
  - SCM Probe
- Plasma current sensor

![Image of LP-POM setup](image3)
Successful Operation of LP-POM

- HTV potential and plasma current was monitored throughout HTV flight (launch to reentry)
- Results are being verified by comparing them with existing physical models and ISS sensors

![Graph showing comparison between data measured by LP-POM and data calculated from the model based on IRI-2016.]

Okumura et al. “Charging of the H-II Transfer Vehicle at Rendezvous and Docking Phase”, Journal of Spacecraft and Rockets

Current Activities on Tether

- “Converging” tether for lowering collision risk
  - Automatically converges in case tether is severed or malfunctions
- Tether survivability estimation

![Image of “Converging” tether]

Example of tether survivability estimation
Current Activities on FEC

- Improvement in emission current density and durability
- Application to electric propulsion

![I-V comparison between KITE and current FEC](image)

Coupling operation with ion engine


Current Activities on LP-POM

- Further investigation of In-orbit data in scientific sense
- Application to debris capturing phase

![Graph showing extraction voltage vs. emitter current](image)

Okumura et al. “Charging of the H-II Transfer Vehicle at Rendezvous and Docking Phase,” Journal of Spacecraft and Rockets
Summary

- Pros and cons of electrodynamic tether (EDT) for ADR were shown

- KITE mission (In-orbit experiment of EDT), conducted in early 2017, was reviewed

- Studies on EDT elements are on-going for enhancing advantages of EDT and for exploiting KITE results to other applications