Electric Solar Wind Sail tether payloads onboard CubeSats

Jouni Envall, Petri Toivanen, Pekka Janhunen

Finnish Meteorological Institute, Helsinki, Finland (jouni.envall@fmi.fi)
Outline

- E-sail & Coulomb drag propulsion.
- Missions enabled by E-sail.
- E-sail tether payloads in CubeSats, general.
- Flight history: ESTCube-1 and Aalto-1.
- Tether production.
- ESTCube-2/3.
- Conclusions.
E-sail

- Charged tether taps momentum by deflecting ion flow of solar wind → “Coulomb drag”.
- One or more tethers.
- Centrifugal force to stretch tethers.
- Auxiliary tethers to stabilize dynamics.
- For 20 kV voltage, $F/l = 0.5 \text{ mN/km}$.
- Positive or negative voltage. With positive $V$, electron gun(s) used to oust excess electrons.
- For $100 \times 20 \text{ km}$ tethers, $F = 1 \text{ N @1 au}$.
- Thrust scales as $1/r$.
- For 1000 kg spacecraft (propulsion system mass $<200\text{kg}$), $\Delta v = 30 \text{ km/s/year}$.
- Power consumption 700 W @1 au.
- Power consumption scales as $1/r^2$. 
E-sail mission examples

- Science missions to the outskirts of the Solar System (or beyond).
- Spiraling inwards to the inner parts of the Solar System.
- Asteroid tours with scientific or commercial outcome.
- Plan: multi-asteroid touring mission by a fleet of (up to 50) CubeSats. (Next presentation by Iaroslav Iakubivskyi)
E-sail & CubeSats

- Typical E-sail mission with CubeSat: 1-3U satellite, single tether (length tens to hundreds of meters; voltage ~1 kV).
- Orbit: so far LEO (ionospheric plasma instead of solar wind).
- Mission objectives: tether deployment by spinning the satellite; observing the Coulomb drag force with a suitable method.
Previous launches, ESTCube-1

- Launched in 2013.
- 1U CubeSat.
- Two filament tether, 16 m.
- Tether voltage ±500 V.
- Two cold cathode e-guns.
- Result of tether mission: failed due to jammed tether deployment system.
Previous launches, Aalto-1

- 3U CubeSat.
- Four filament tether, 100 m.
- Tether voltage ±1000 V.
- Four cold cathode e-guns.
- Result of tether mission: Pending.

Aalto-1

Tether board

High voltage board
Tether production

- E-sail tether requirements: high electrical conductivity; sufficient mechanical strength; suitable thermal characteristics; low mass; *multifilament* etc.

- Novel tether production facility under development (PI Envall). Ladder shaped tether, metal wires, cold welded bonds. Wire thickness 20 µm to 35 µm.

![](image)

1 2 ... N
N ≥ 2

Direction of deployment
Tether production (2)
ESTCube-2/3

• Both Coulomb drag test CubeSats thus far have remained at LEO → no solar wind plasma.
• ESTCube-3 to be the first to reach solar wind, e.g. lunar orbit or Lagrange point (L1, L2).
• ESTCube-2 will test novel key technologies of EC-3 in LEO. These include CubeSat compatible cold gas thrusters, star tracker based attitude determination system and high speed telecommunications system.
• Also additional LEO data received from ESTCube-2 (plasma brake).
• Satellites are close to identical by design.
• Tether length 300 m, voltage −1 kV…+6 kV.
• Expected Coulomb drag force in solar wind: 60 µN.
ESTCube-2/3 (2)

Launch lock × 3

Tip mass

Tether reel

Tether deployment

E-guns (place holder)
# ESTCube-2/3, tether PL mass

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supporting structure</td>
<td>133</td>
</tr>
<tr>
<td>Control board PCB</td>
<td>29</td>
</tr>
<tr>
<td>Control Board Electronics</td>
<td>20</td>
</tr>
<tr>
<td>Launch Locks</td>
<td>12</td>
</tr>
<tr>
<td>Tether Chamber</td>
<td>68</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>10</td>
</tr>
<tr>
<td>Tip mass</td>
<td>3</td>
</tr>
<tr>
<td>Tether Reel, incl. Tether</td>
<td>34</td>
</tr>
<tr>
<td>Reel Adapter</td>
<td>2</td>
</tr>
<tr>
<td>Reel Motor</td>
<td>48</td>
</tr>
<tr>
<td>Bus Connector(s)</td>
<td>8</td>
</tr>
<tr>
<td>HV PCB and electronics</td>
<td>58</td>
</tr>
<tr>
<td>Screws and Fasteners</td>
<td>25</td>
</tr>
<tr>
<td>Misc (cabling, adhesives etc.)</td>
<td>15</td>
</tr>
<tr>
<td><strong>Sum</strong></td>
<td><strong>465</strong></td>
</tr>
<tr>
<td><strong>Margin, 20%</strong></td>
<td><strong>93</strong></td>
</tr>
<tr>
<td><strong>Total with margin</strong></td>
<td><strong>558</strong></td>
</tr>
</tbody>
</table>
Conclusions

- Test missions of E-sail tether hardware have begun in 2013 (launch of ESTCube-1).
- A lot of progress has taken place on ground (novel tether topology, in-house production of tether, improved flight mechanics and diagnostics etc.)
- First proper test results from orbit are still waited for.
- Tether mission of Aalto-1 expected to start during summer.
- Next ESTCube satellites are already in development phase.
- ESTCube-3 is expected to be the first spacecraft to demonstrate the use of solar wind for spacecraft propulsion.