7th International Conference on Tethers in Space

EDT Demonstration for Keeping Low Altitude Orbit Using Carbon Nanotube Tether

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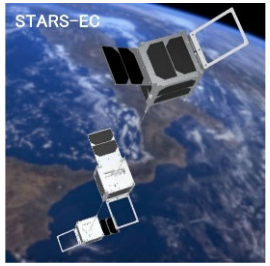
STARS PROJECT
Tether, Robotic satellite, Mother & daughter (& climber)

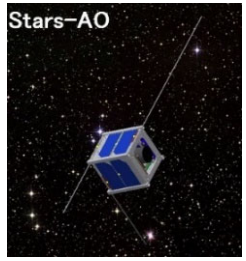
Chanctreistics: Space tether, Rbotic satellite, Mother & daughter (& climber)

Waiting for shipping



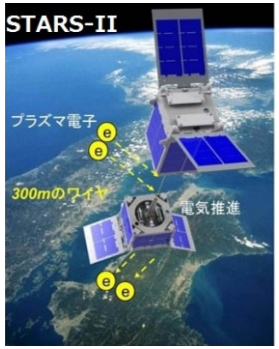
Released from the ISS
on Mar. 14, 2021
Decayed
Mini-Space elevator demonstration

Released from the ISS
on Oct. 6, 2018
Decayed
Mini-Space elevator demonstration

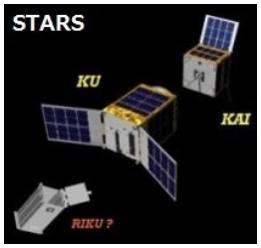


Launched
on Oct. 29, 2018
Under operation
- ✓ High resolution camera
- ✓ High speed trans.

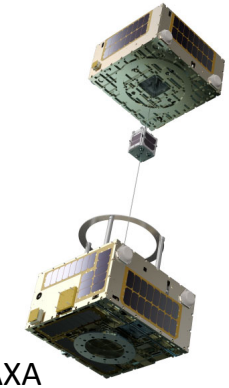
Released from the ISS
in 2016
Decayed
- ✓ 100m long tether
- ✓ Kevlar tether



Launched in 2014
Decayed
- ✓ 300m long tether
- ✓ Electro-Dynamic tether



Launched in 2009
Still alive
- ✓ Mother & daughter
- ✓ Tethered satellite
- ✓ Robotic satellite



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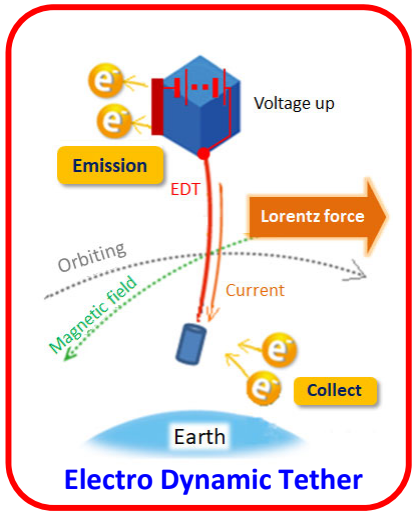
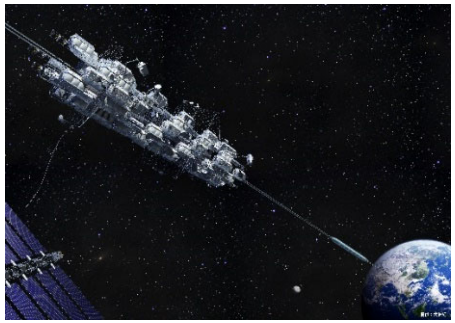
Innovative satellite 3
STARS-X waiting for shipping

Long Tether extension
Climber moving
Debris capture



Electro Dynamic Tether

Future



Space elevator (© Obayashi corporation)

Other applications

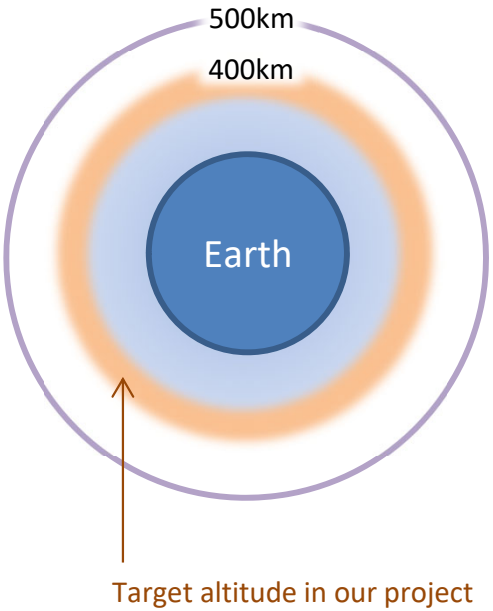
- Operation on extremely low earth orbit
- Orbital transfer Elevator (Skyhook, etc.)
- Formation Flight by tether
- Electrical power generation by EDT
- Artificial small gravity

SPACE MECHANICAL DYNAMIC CONTROL SYSTEM

EDT Demonstration for Keeping Low Altitude Orbit Using Carbon Nanotube Tether

Background

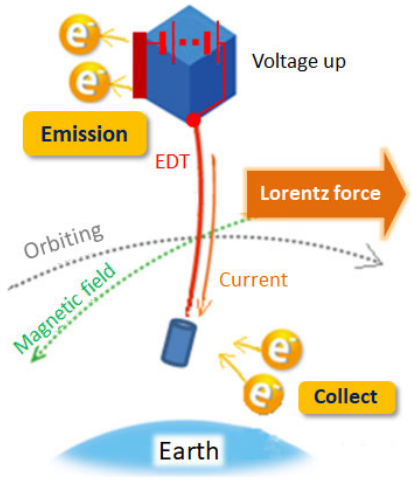
Earth orbits at altitudes of 400 to 1000 km are usable, and are extremely congested, requiring satellite design and operation that takes space debris prevention into consideration.
Although it is suitable for debris suppression at altitudes below 400 km, its orbital life is short due to large atmospheric drag.
>>> By extending the orbital life at an altitude of about 400 km, the effective utilization of space will be accelerated.



Proposal

Utilizing effect of electric propulsion with an electrically conductive tether (EDT), the orbit lifetime around 400km altitude is expected to be extended.

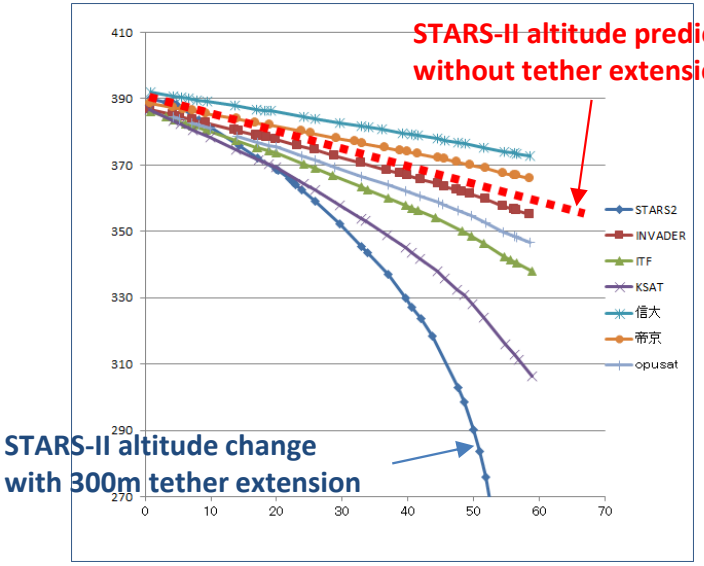
- EDT electric propulsion is possible using only electrical energy.
- Satellites at altitudes below 400km will re-enter the atmosphere in a short period of time, so the probability of collision is lower than at altitudes above 400km.
- If it becomes debris due to a malfunction or end of life, it can re-enter the atmosphere in a short period of time.
- Observation resolution increases because the altitude is lower and closer to Earth.



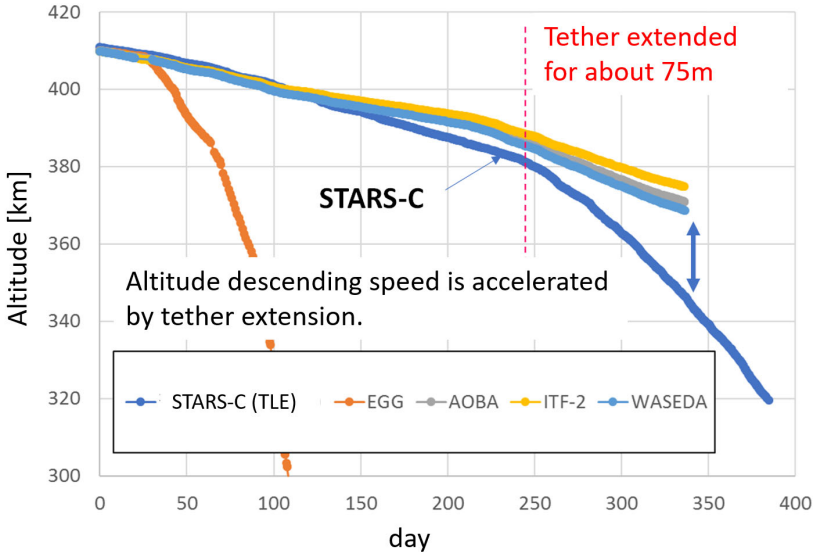
Proposed technology

The conductive tether is extended and stabilized in the earth direction by the gravity gradient. By emitting electrons from an electron emitter mounted on a higher-altitude satellite and collecting electrons on a lower-altitude one, a current is generated from the higher-altitude to the lower-altitude. According to Fleming's law, the Lorentz force is generated in the direction of the orbiting and accelerates, so it can be propelled in the upward direction of the orbit.

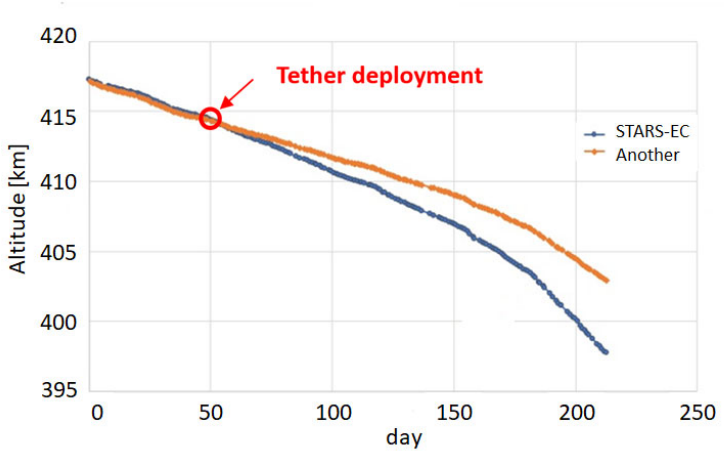
Reference: Altitude descending by atmospheric drag (results from STARS satellites)



STARS-II: 10kg satellite launched in 2014
Electrodynamic tether (aluminum ϕ 0.15mm x12 & stainless ϕ 0.1mm x6)
Extended for 300m

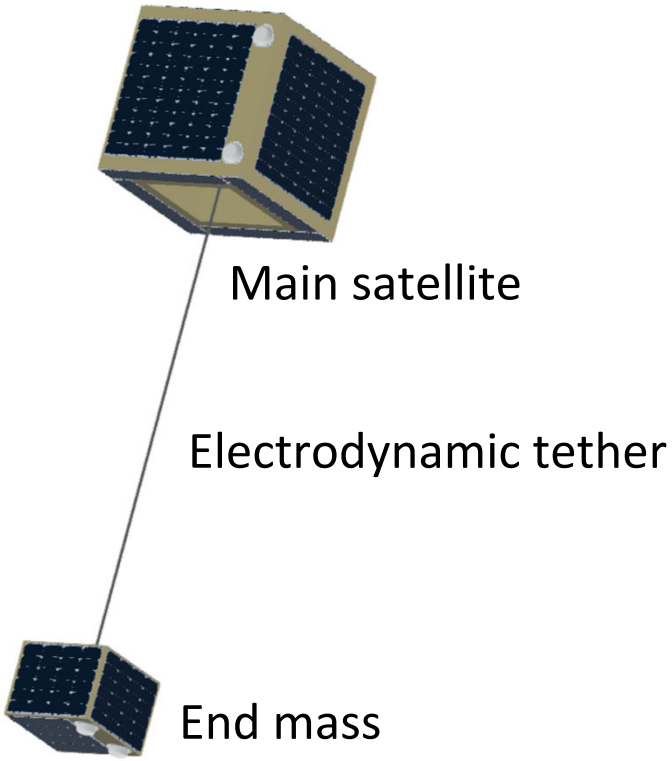


STARS-C: 2U cube-sat launched in 2016
Kevlar tether (ϕ 0.4mm)
Extended for about 75m



STARS-EC: 3U cube-sat launched in 2021
Steel convex tether (6mm width tape)
Extending for 10-20m

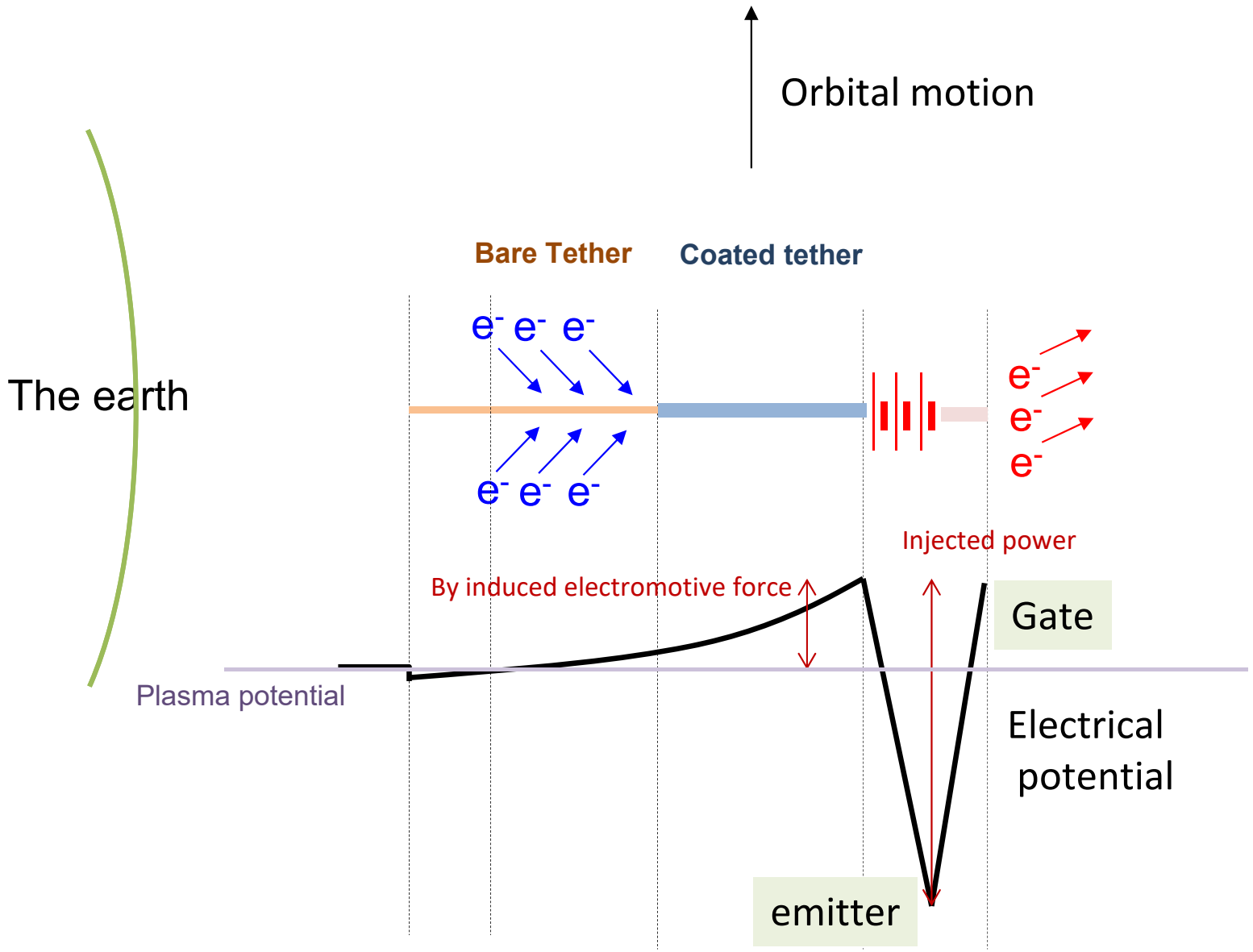
EDT satellite Concept



By generating a current through the conductive tether, a Lorentz force that overcomes air drag is generated.
> Orbital altitude changes by electrical thrust are expected.

- Extend a conductive tether in orbit to collect electrons from plasma around the end mass and emit electrons from the main satellite. The current is expected to be passed through the tether.
- The material for the conductive tether that collects electrons will be carbon nanotube (CNT), which has both the flexibility and conductivity of chemical fibers.
- A highly efficient field emission cathode (FEC) will be used as the electron source for electron emission, and its performance will be evaluated in orbit.
- Control the voltage applied to the electron source and the number of elements that emit electrons, making it possible to adjust the magnitude of the current.

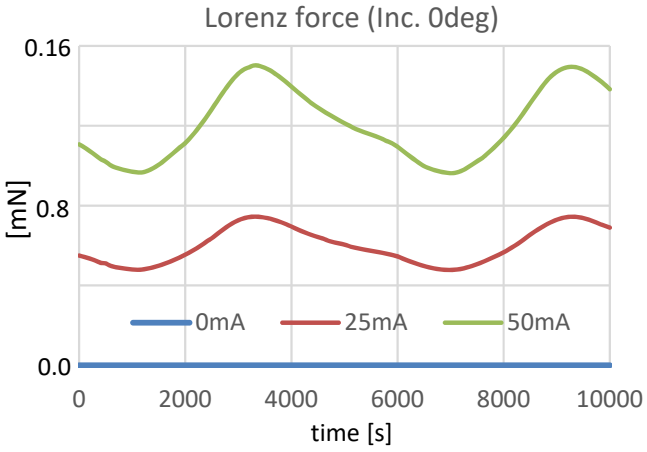
Electrodynamic tether system

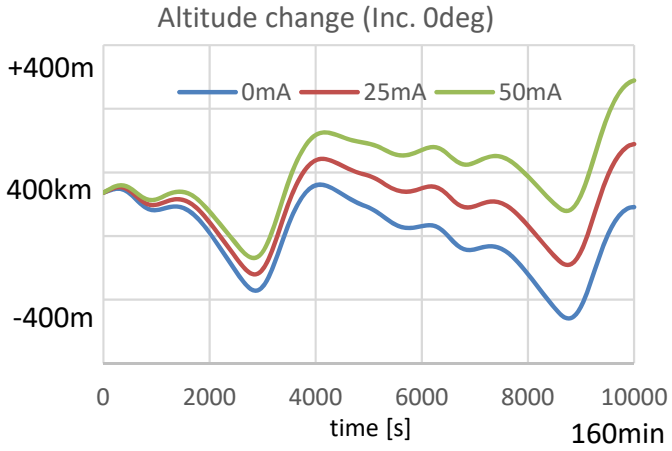


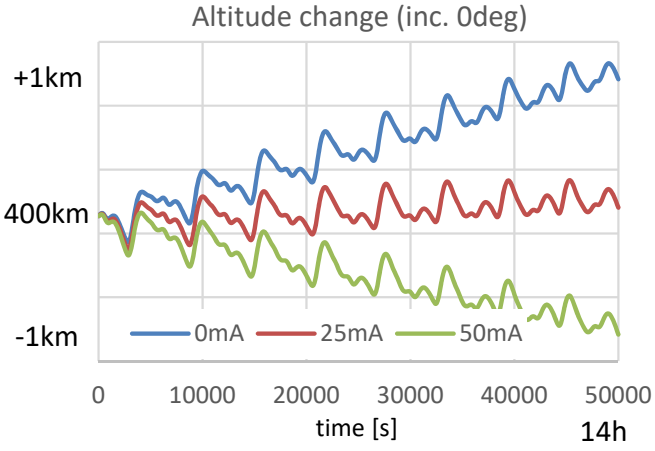
Orbital simulation for EDT

Tether length: 1000m, radius: 1.15mm

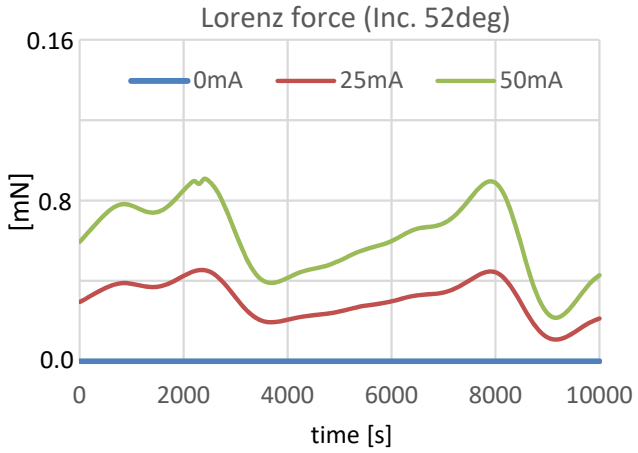
Inclination = 0deg

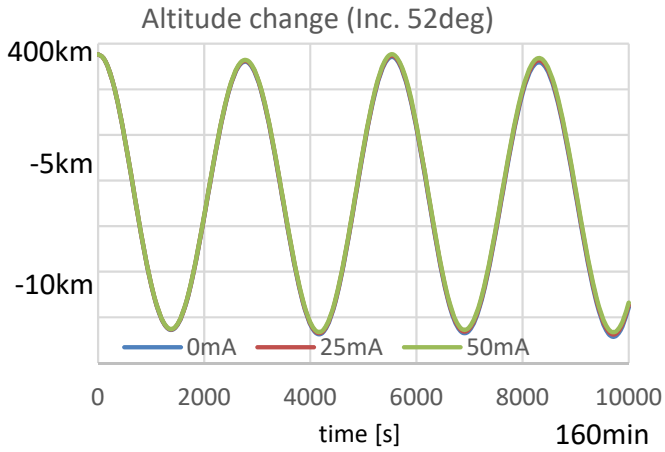


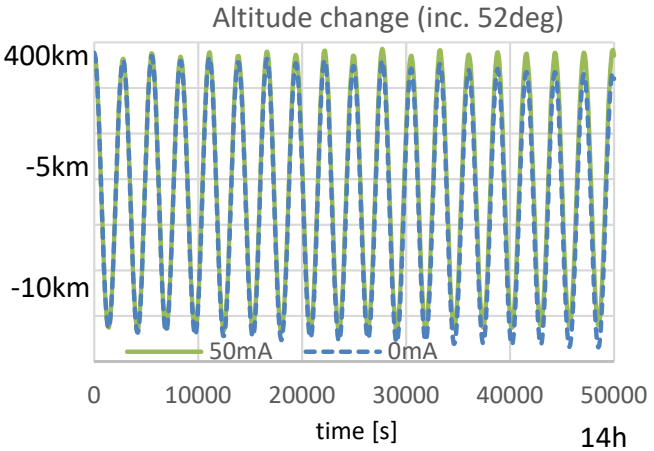




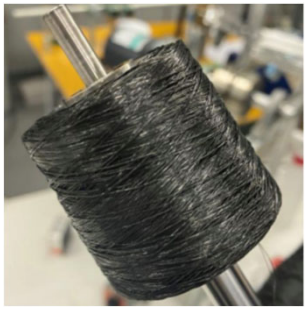
Inclination = 52deg







Manufactured tether materials

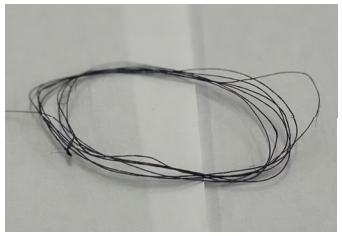


Prototype spec.

Tether radius	0.3[mm]
Density	3.540×10^{-4}[kg/m]
Electrical resistance (Silver coating 2μm)	82.06[Ω/m]

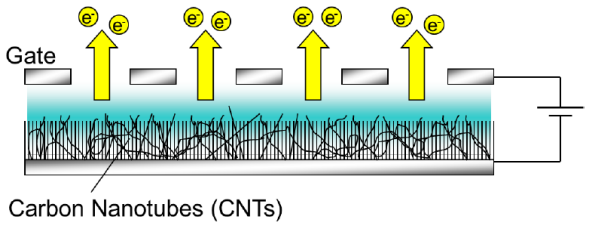
Estimation from each material spec.

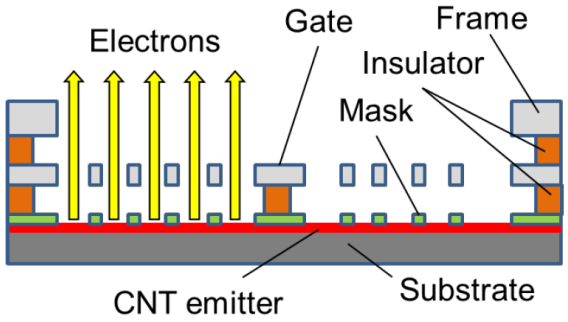
	CNT	Copper	Aluminum
Length [m]	1000	1000	1000
Radius [m]	0.00115 (0.3mm x 10pieces)	0.00115	0.00115
Mass [kg]	3.55	6.31	1.91
Resistance [ohm]	**8206.0**	**21.9**	**35.4**
Strength [N]	**60**	**155.5**	**70.5**

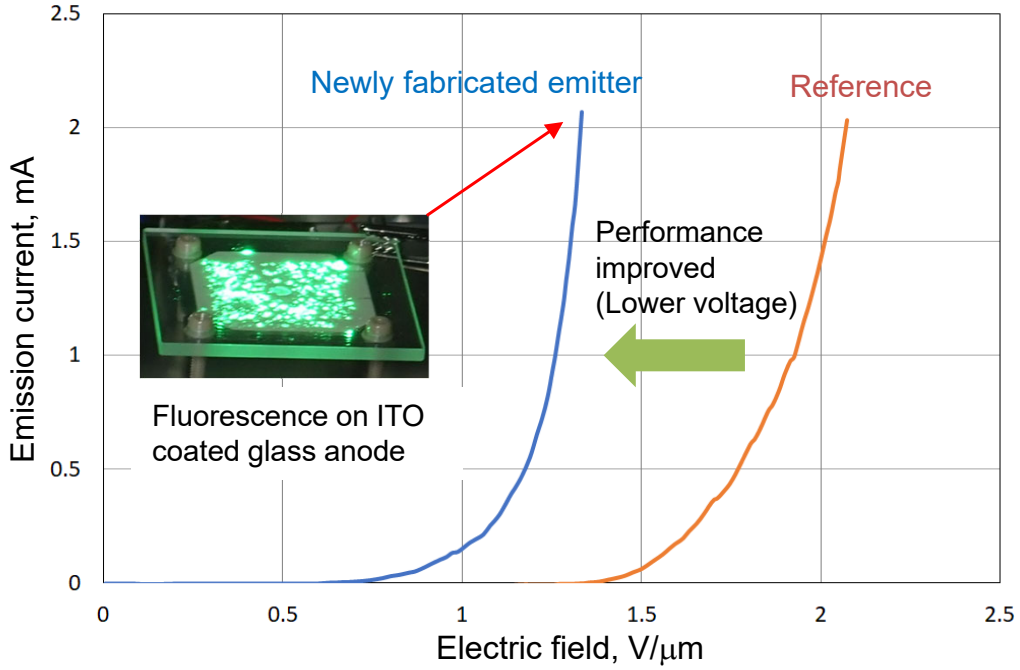


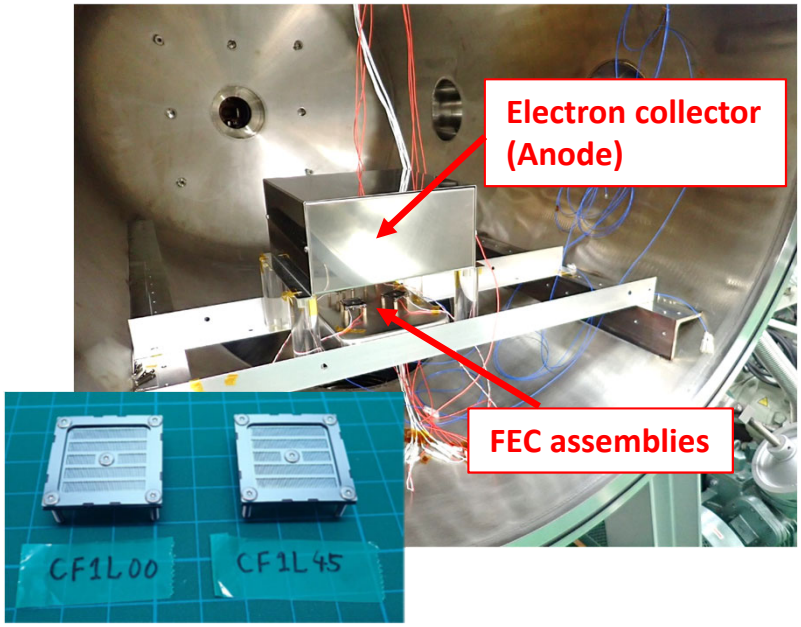
Flexible !! *But improvements to be small resistance are necessary*

FEC experimental results

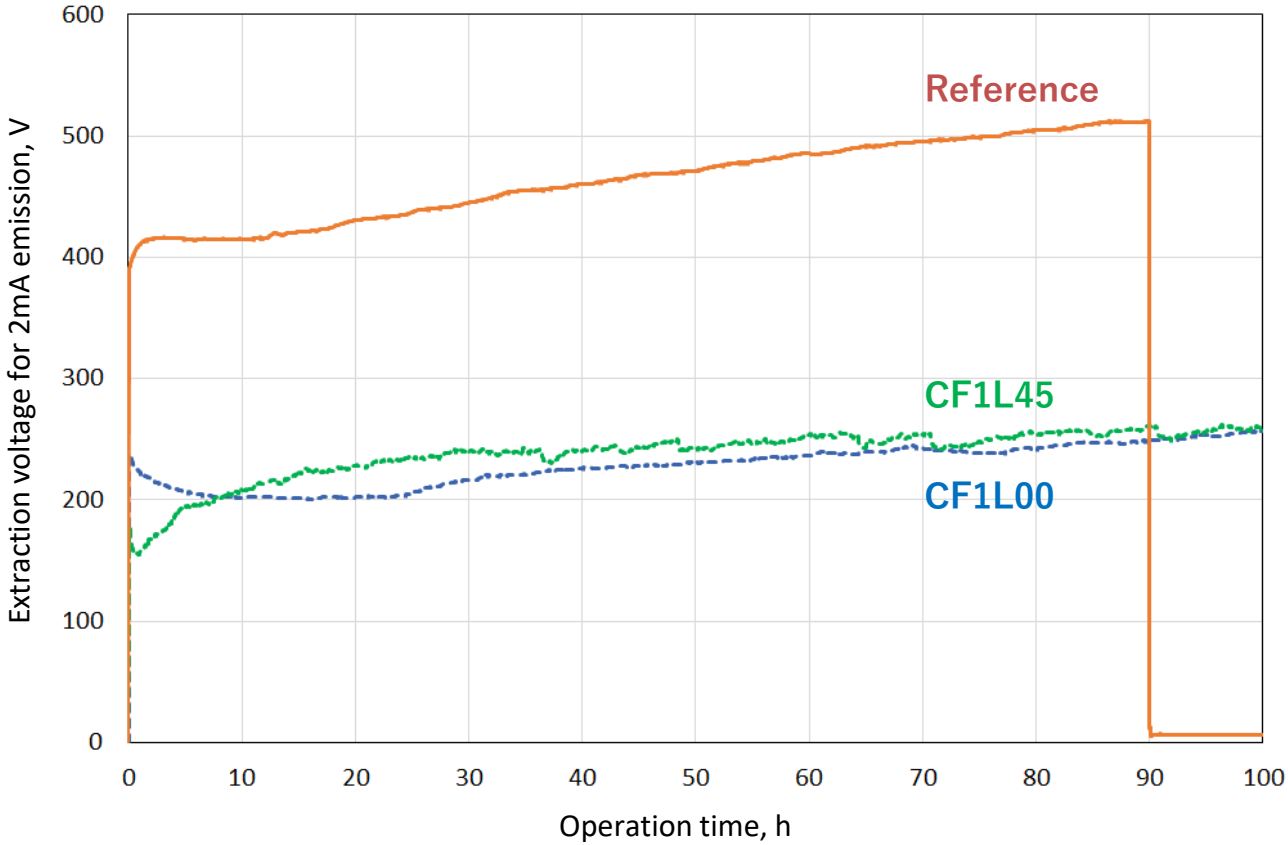






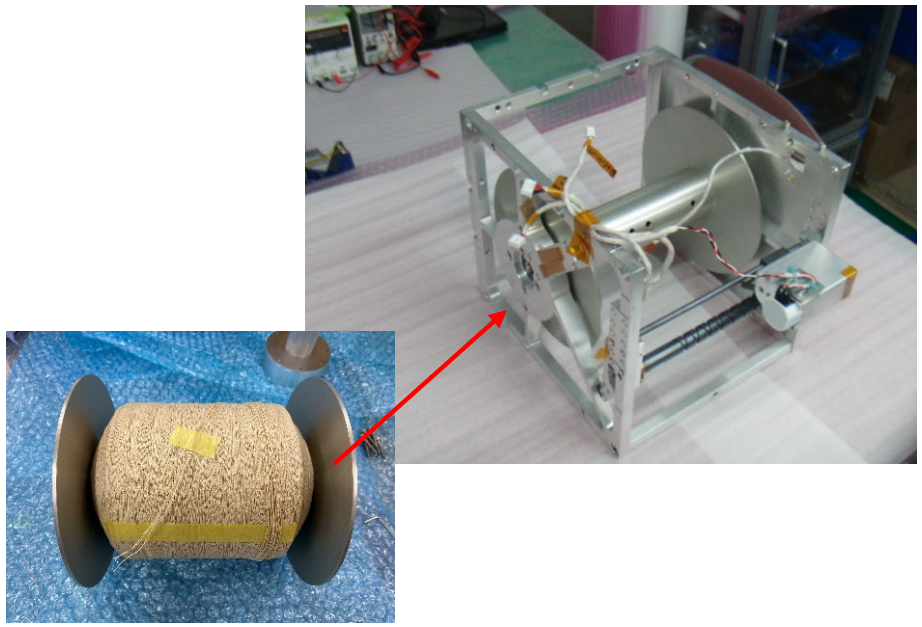


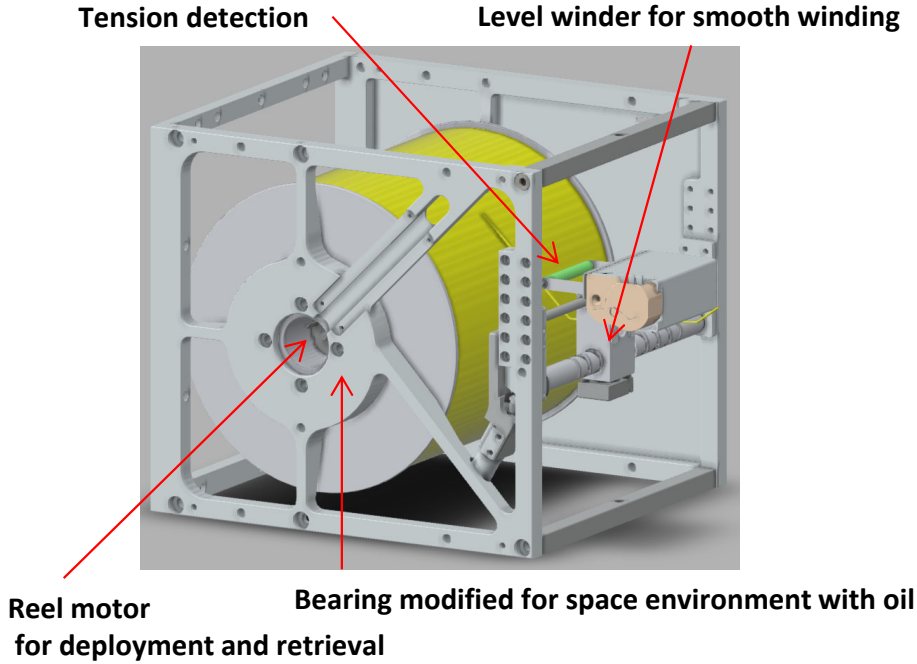
Long term experiment for FEC



Good results were obtained for CF1L45 and CF1L00.
(A large voltage was required with the reference)
But the rate of voltage are increasing.
Also, further improvements are necessary for use in atomic oxygen.

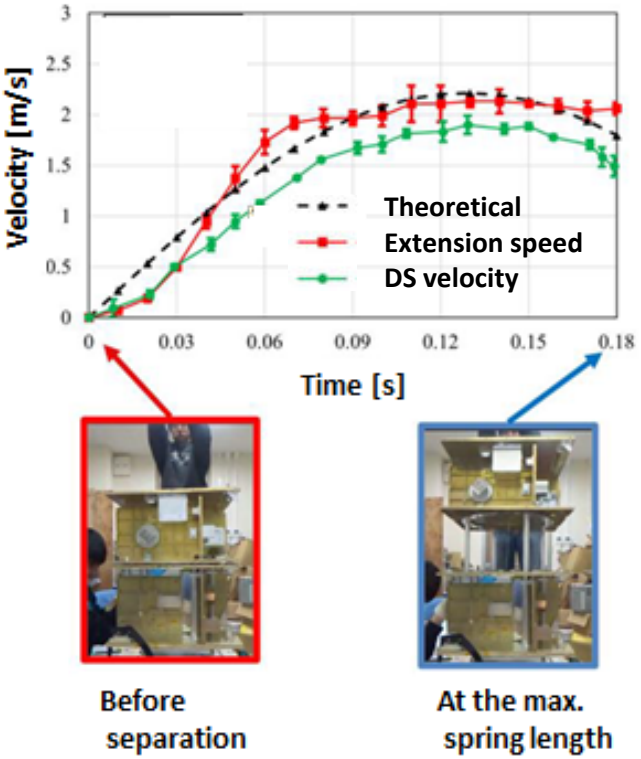
Tether reel system for deploy and retrieve

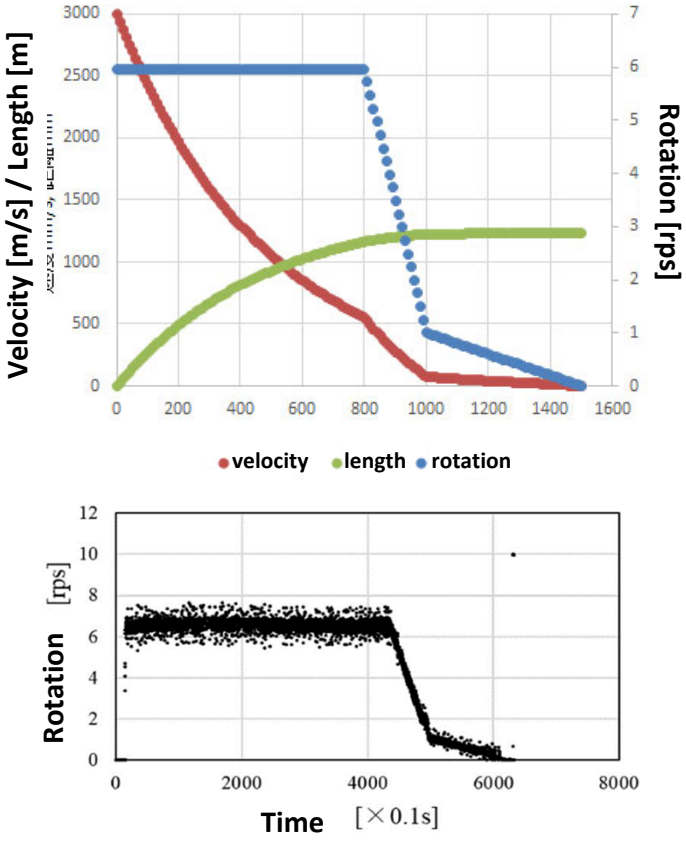


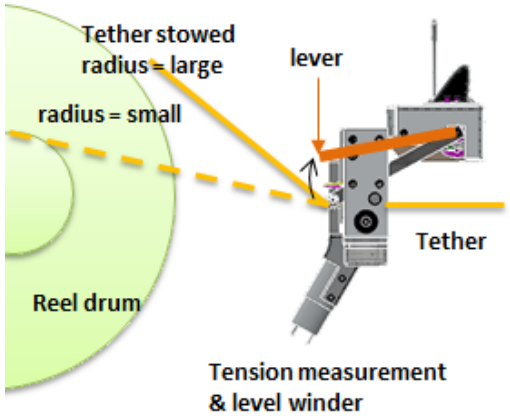


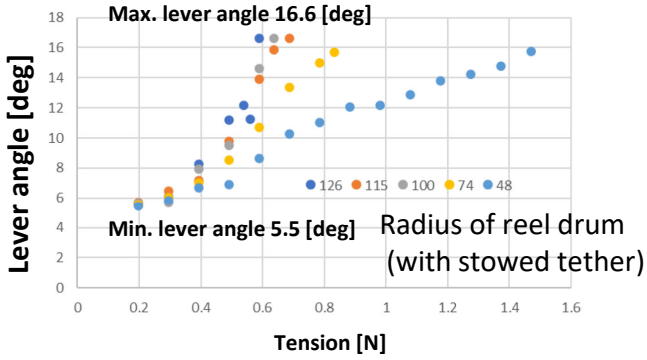
Evaluated by the ground experiment using Vectran tether

Experimental Data for Reel system







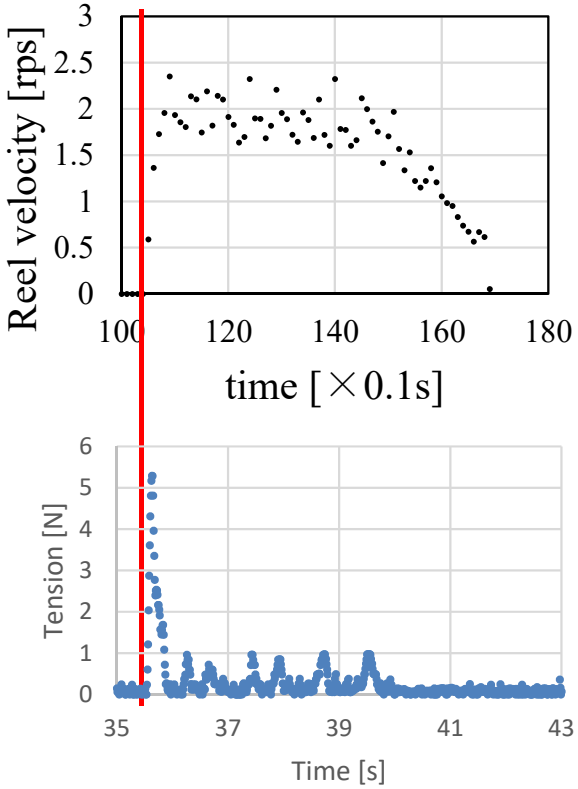


Radius of reel drum (with stowed tether)

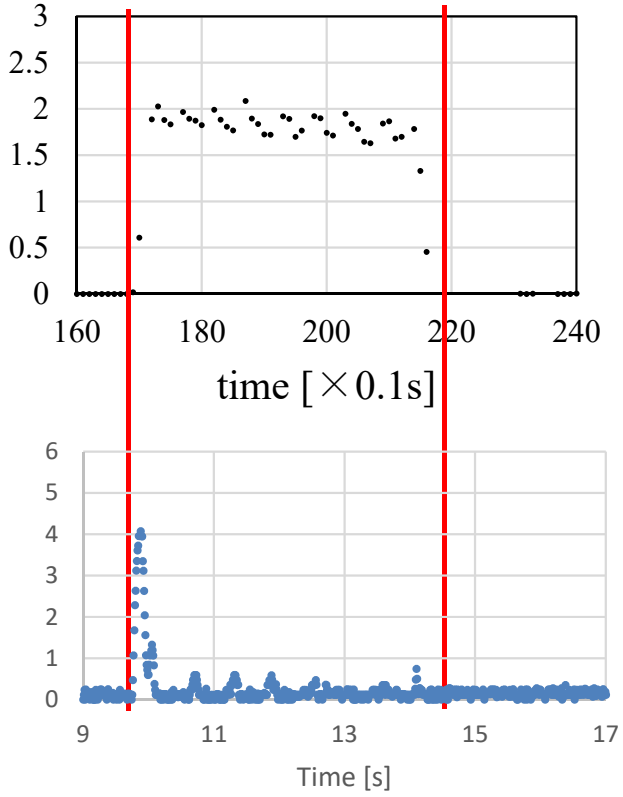
Air floating experiment

With Vectran tether

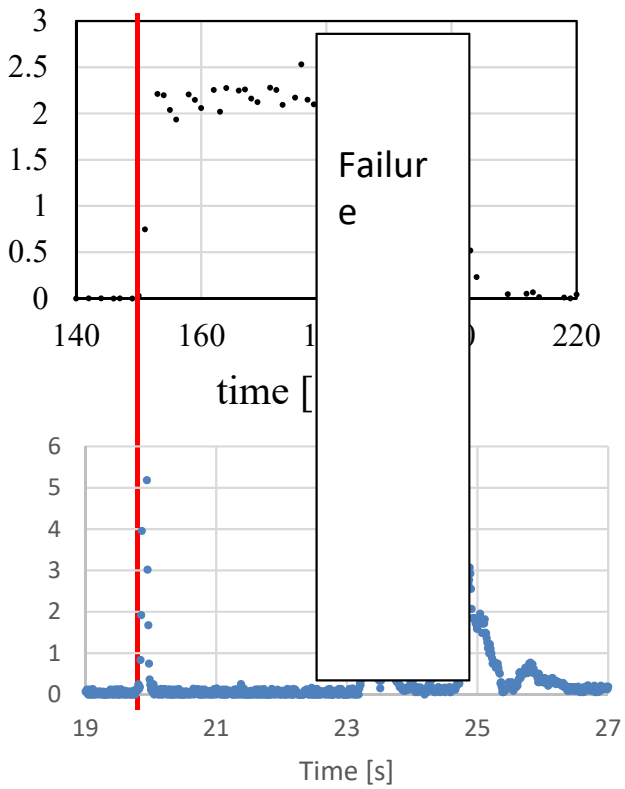
Without motor control



Motor by 8% duty

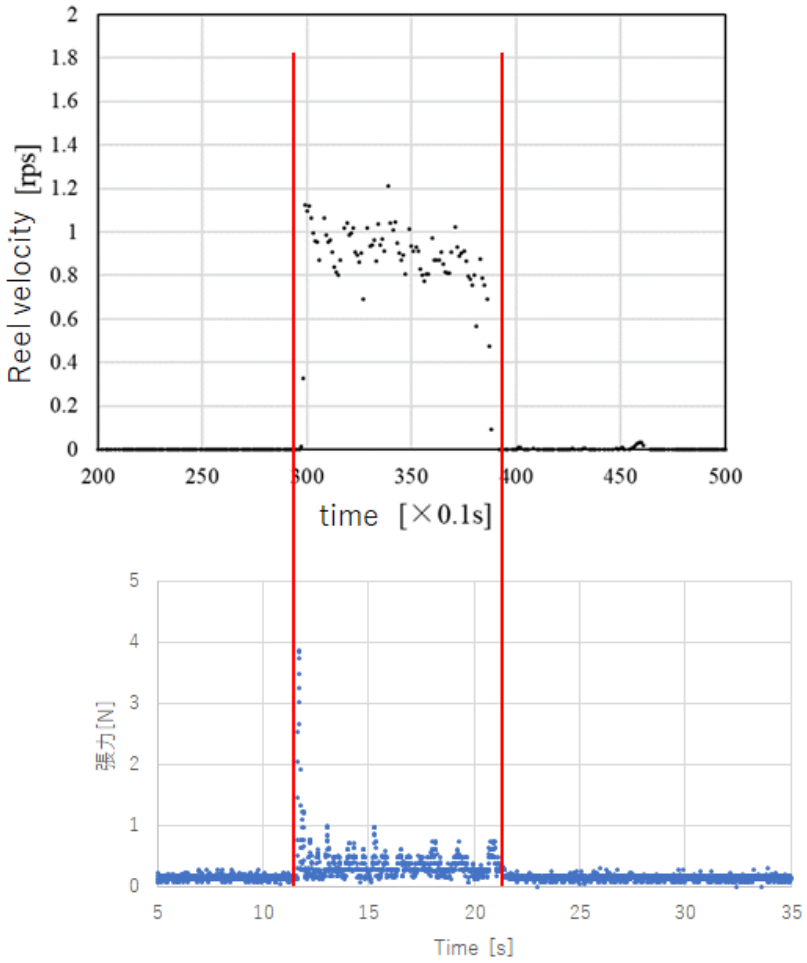


Motor by 10% duty

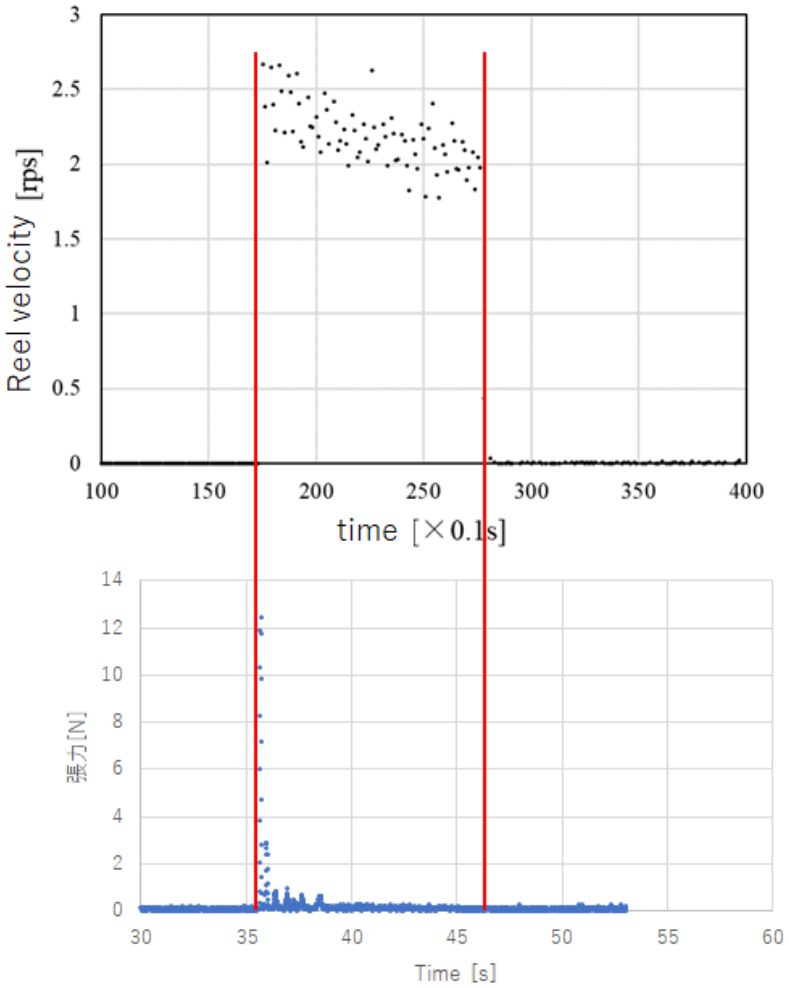


Influence by reel radius (tether storage amount)

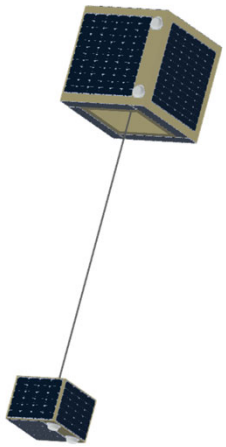
6% duty & ϕ126mm



8% duty & ϕ48mm



Satellite development project

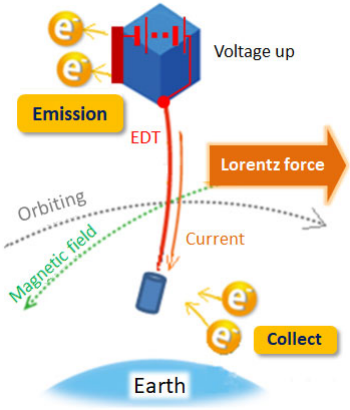


Spec.	
Mass	50 [kg]
Scale	600 x 600 x 600 [mm]
Power	84W
COM	2GHz Two ex. stations (Ground: CRESST) *Main satellite & End mass have each com. system
ADC	3 axis attitude control (RW, MTQ) Gravity gradient stabilization (by tether extension)
Tether	**Electrodynamic tether 1000m**
FEC	**Electron emitter: 50mA**

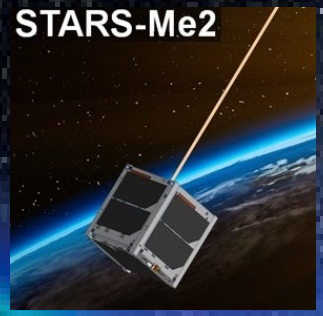
Level	Success criteria	Verification
Minimum	• EDT 1000m extension • Electron emitter activation (component function) • Induced electromotive force (Voltage of the tether end from sat. body. Then tether extension direction is confirmed)	• GPS data • Applied voltage & current flow • Voltage
Full	• Electron emission from the emitter • Tether current flow control (Emitter activation control) • Orbital transfer by Lorenz force	• Current measurement • Current measurement • TLE data
Advanced	• Keeping altitude (Lorenz force > atmospheric drag) • Control orbital transfer (by active tether current control)	• TLE data • TLE & tether current

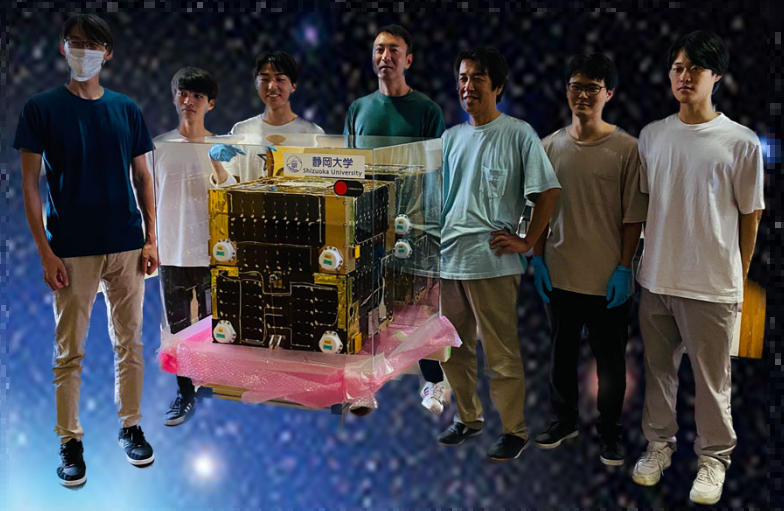
Summary (current situation)

- Inc. 52deg & Altitude 400km
  is possible to keep
  by 1km tether with 50mA current
- Pico-satellite has been designed.



- Challenges
  - CNT tether with small resistance
    - 1000 Ohm/km
      - coating, manufacturing, etc.
  - FEC tolerance to atomic oxygen
    - 1 year lifetime
      - on/off control, mounting position, chemically, etc.





Thank you very much for your attentions