May 25, 2016

Development of Commodity for removal of expended elements using Electro-dynamic Tether

ESTEC, Clean Space Industrial Days

Re-entry technologies

Non demisable S/C → Controlled reentry → High thrust until reentry

Solid propulsion module
- Additional dry mass
- Additional fuel mass

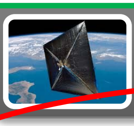
Non restartable Liquid propulsion
- Additional dry mass
- Additional fuel mass

Re-startable liquid propulsion
- Minimum dry mass
- Additional fuel mass

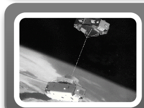
Demisable S/C → Uncontrolled reentry → Final reentry by atmospheric drag

Increase S/C mass with design for demise above 1 Ton

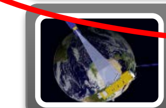
Low and sustainable thrust



Drag augmentation
- Additional dry mass
- Commodity for S/C



Tether
- Additional dry mass
- Commodity for S/C

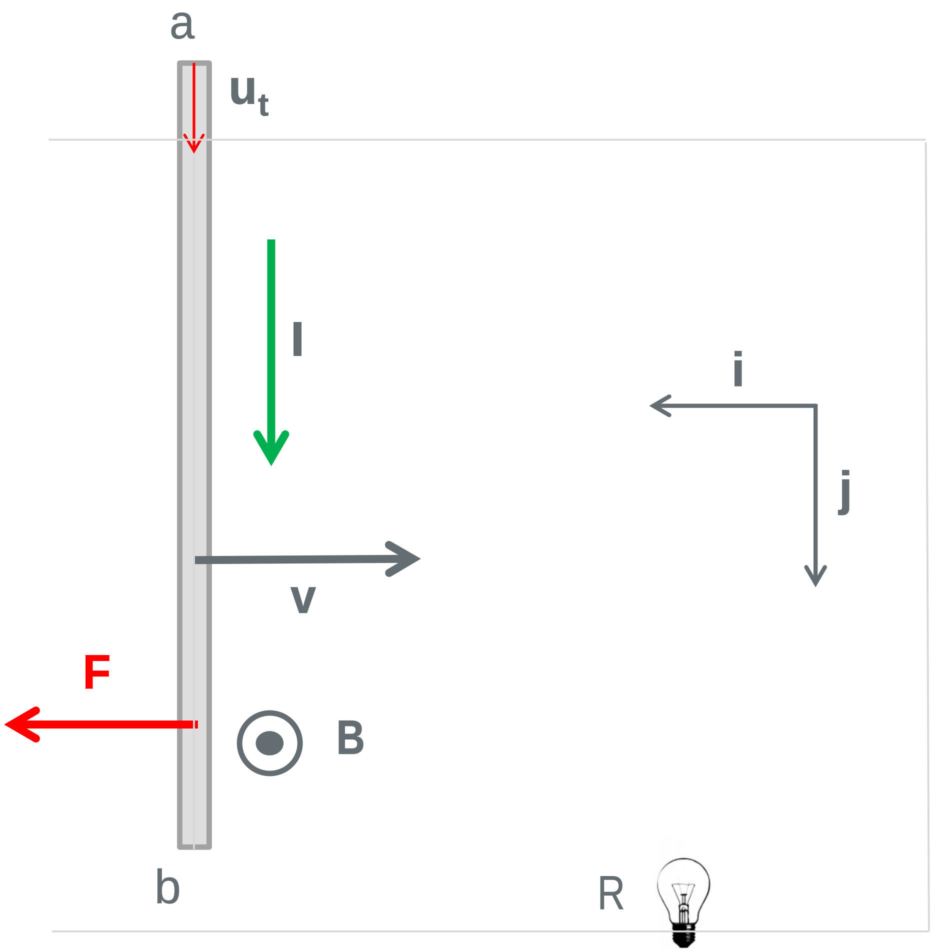


Contact-less propulsion
- Dedicated S/C and rendez vous
- Dedicated mission

Electric propulsion
- Additional dry mass
- Commodity for S/C

Chemical propulsion
- Additional mass
- Reduce S/C height to a low orbit

Electrodyamic tether Fundamentals



- Faradays' Law

$$\Phi_{ab} = \int_a^b \mathbf{E}\cdot d\mathbf{l} = -\frac{\partial}{\partial t}\int_S \mathbf{B}\cdot d\mathbf{S} = \boxed{-LB_0 v}$$

- Ohm's Law:

$$I = \frac{\Phi_{ab}}{R} \quad \rightarrow \mathbf{I} = \frac{LB_0 v}{R}\mathbf{j}$$

- Lorentz force

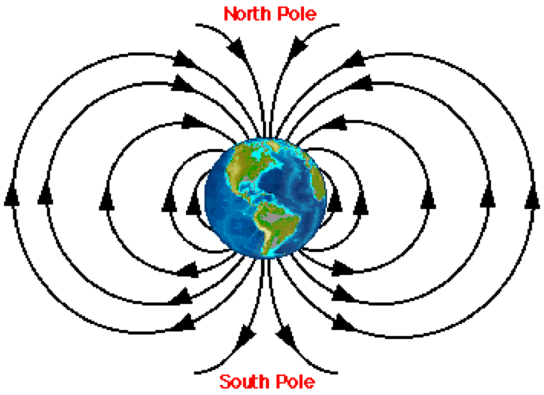
$$\mathbf{F} = \int_0^L I(s)\mathbf{u}_t \times \mathbf{B} ds = ILB_0\mathbf{i}$$

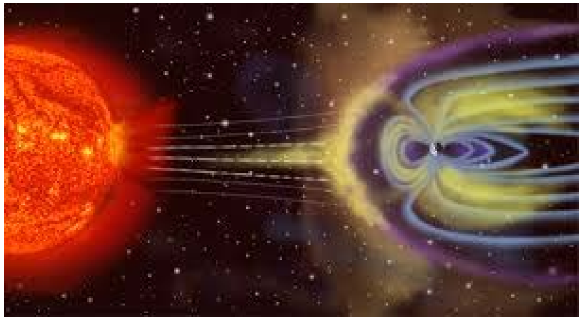
No battery, no propellant, passive process based on Thermodynamics principles

Keeping Earth Clean by Natural environment

Tether uses three main characteristics of Sun-Earth system:

- Earth magnetosphere, magnetic field. Induce voltaje and force
- Earth ionosphere (60-600 km and beyond), atmosphere is ionized by solar radiation (e- + H+ + O+). Create the current
- Gravity gradient. Maintain tether in local vertical attitude.





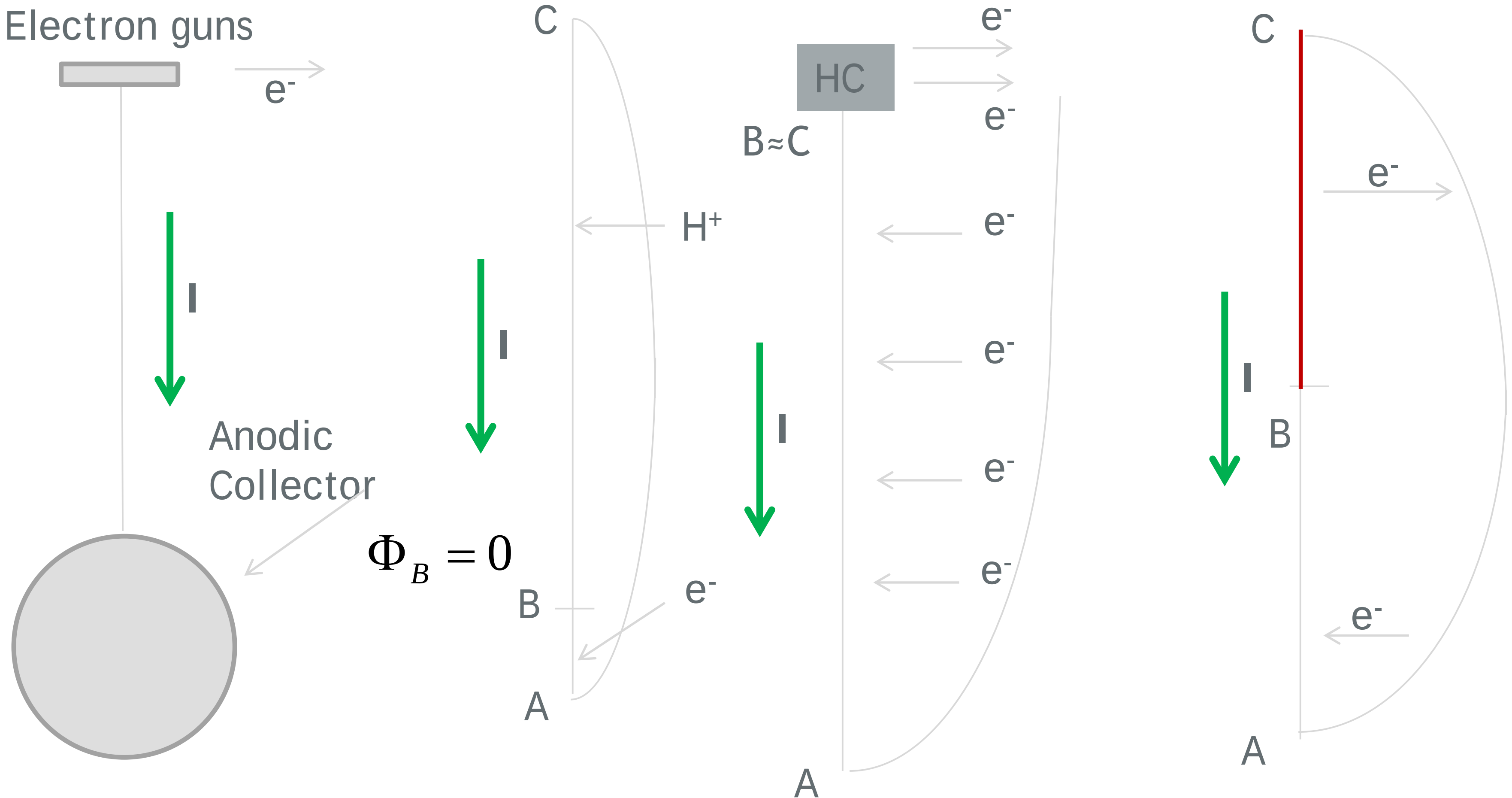
Types of electrodynamic tethers

Insulated tether

Bare Floating Tether

Bare tether with HC

Bare-thermionic tether



TSS-1 and TSS-1R

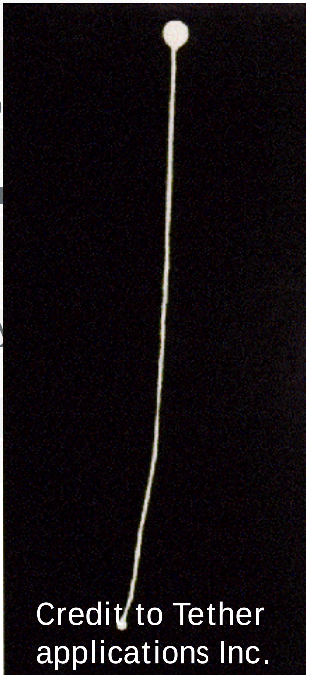
Past Tether Missions

TSS-1R deploys from Shuttle, 1996


Credit to NASA

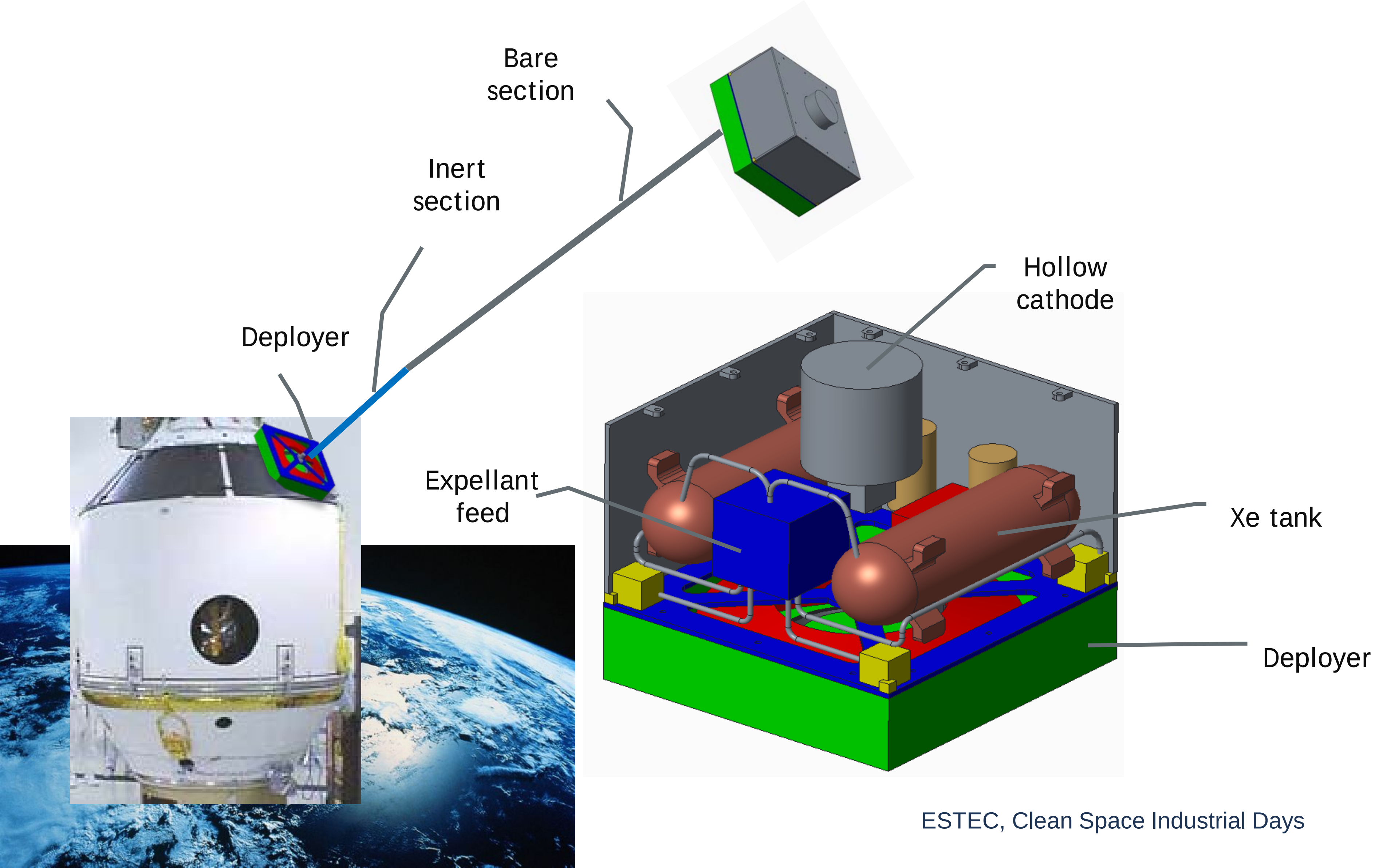
Name	Year	Orbit	Length	Agency	Commen
Gemini 11	1967	LEO	30m	NASA	Spin stabilized,0.15rpm
Gemini 12	1967	LEO	30m	NASA	Local Vertical, stable swi
H-9M-69	1980	Suborb	500m	NASA	Partial Deployment
S-520-2	1981	Suborb	500m	NASA/ISAS	Partial Deployment
Charge-1	1983	Suborb	500m	NASA/ISAS	Full Deployment
Charge-2	1984	Suborb	500m	NASA/ISAS	Full Deployment
Oedipus-A	1989	Suborb	958m	Canada/ NRC/NASA	Spin stabilized, 0.7rpm, **B**
Charge-2B	1992	Suborb	500m	NASA	Full Deployment
TSS-1	1992	LEO	260m	NASA/Italian SA	Partial Deployment, and reel in
SEDS-1	1993	LEO	20km	NASA	Full Deployment, swinging and cut
PMG	1993	LEO	500m	NASA	Upwards deployment
SEDS-2	1994	LEO	20km	NASA	Full deployment, local vertical stab
Oedipus-C	1995	Suborb	1km	Canadian NRC/NASA	Spin stabilized, 0.7rpm, **B-**aligned
TSS-1R	1996	LEO	19.6km	NASA/Italian SA	Almost full deployment , electric-a
TiPS	1996	LEO	4km	NRO/NRL	Tether flying during 11 years
ATEx	1999	LEO	6km	NRL	Partial deployment
ProSEDS*	2003	LEO	15km	NASA	H/W manufactured but it did not fl
MAST	2007	LEO	1km	NASA	Deployment was cancelled
YES2	2007	LEO	32km	ESA	Full Deployment
T-REX	2010	Suborb	300m	JAXA	Full Deployment

SEDS-2 in orbit pictured from the ground in 1994


Credit to Tether applications Inc.

20 systems were built of which 19 flew in space, 11 successful

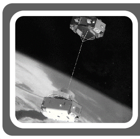
Electro dynamic Tether Deorbiting Unit. T-EDU



Tether performances. Comparison of technologies

Drag augmentation

- Assumed 0,7 g/m2 mass (optimistic number)



Tether

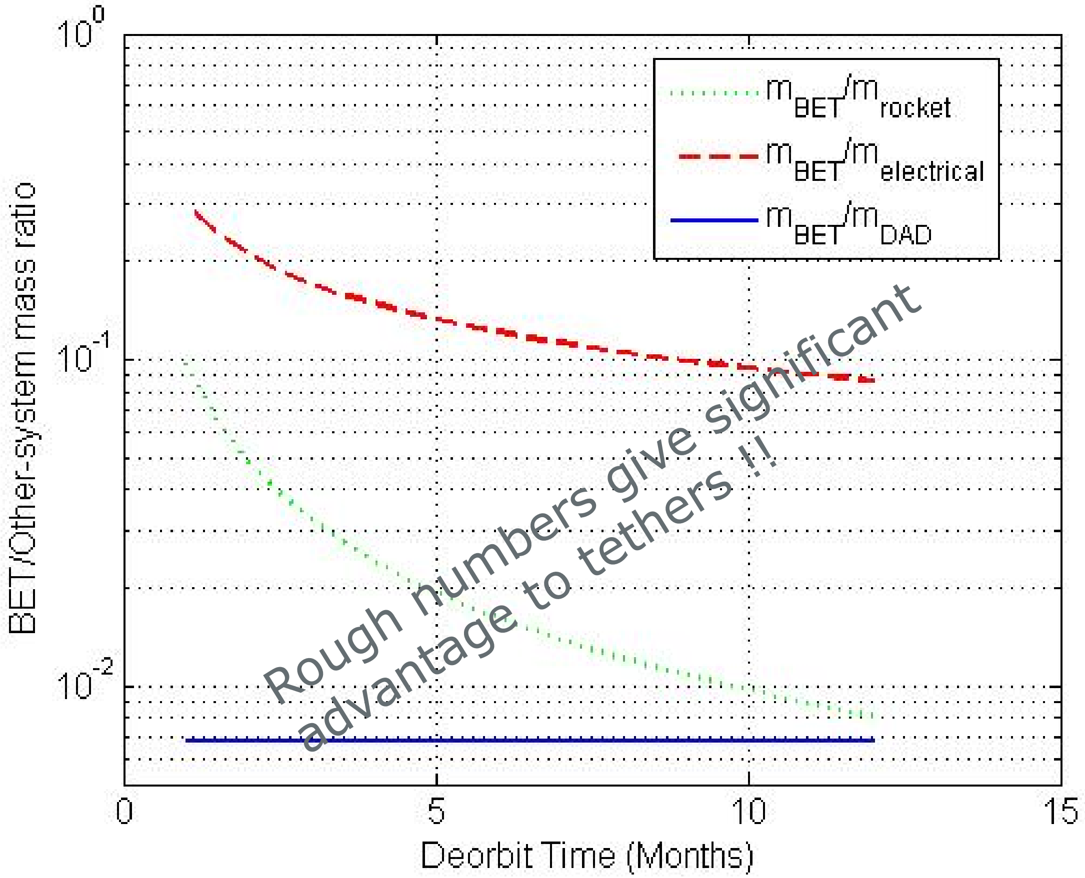
- Assuming equipment mass proportional to tether dimension

Electric propulsion

- Based on state of the art propulsion
- Typical performance values assumed

Chemical propulsion

- Based on SPADES study
- Typical solid booster performance



Rough numbers give significant advantage to tethers !!

See AIAA Proceedings May 2016.
Comparison of Technologies for De-orbiting Spacecraft From Low-Earth-Orbit at End of Mission by Dr. G. Sánchez-Arriaga , J. R. Sanmartín, E. C. Lorenzini

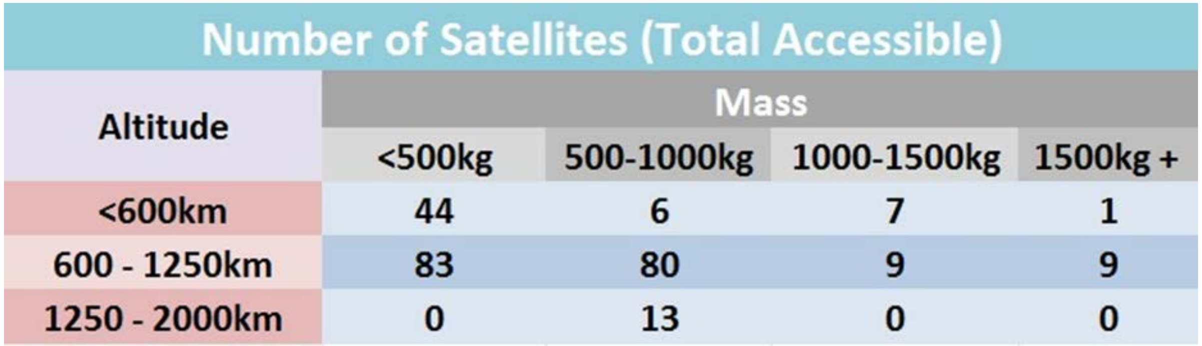
Electro-dynamic tether initial application target

Application objectives:

- Payload adaptors
- Last stages of launchers
- Short mission duration S/C in LEO above 500 kg mass

Host vehicle requirements (for IOD and first version of SS)

- Orbits below 1200 km altitude
- Deorbit within days after launch
- Payloads or stages with their own ACS to allow tether safe deployment



Number of Satellites (Total Accessible)

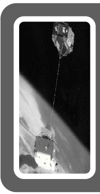
Altitude	Mass			
	<500kg	500-1000kg	1000-1500kg	1500kg +
<600km	44	6	7	1
600 - 1250km	83	80	9	9
1250 - 2000km	0	13	0	0

International market between 2014-2023
(ESA Clean sat presentation 06/05/2014)

Comparison of performances of a given unit

Drag augmentation

- Assumed 100 g/m2 mass
- Deorbit less than 1 year



Tether

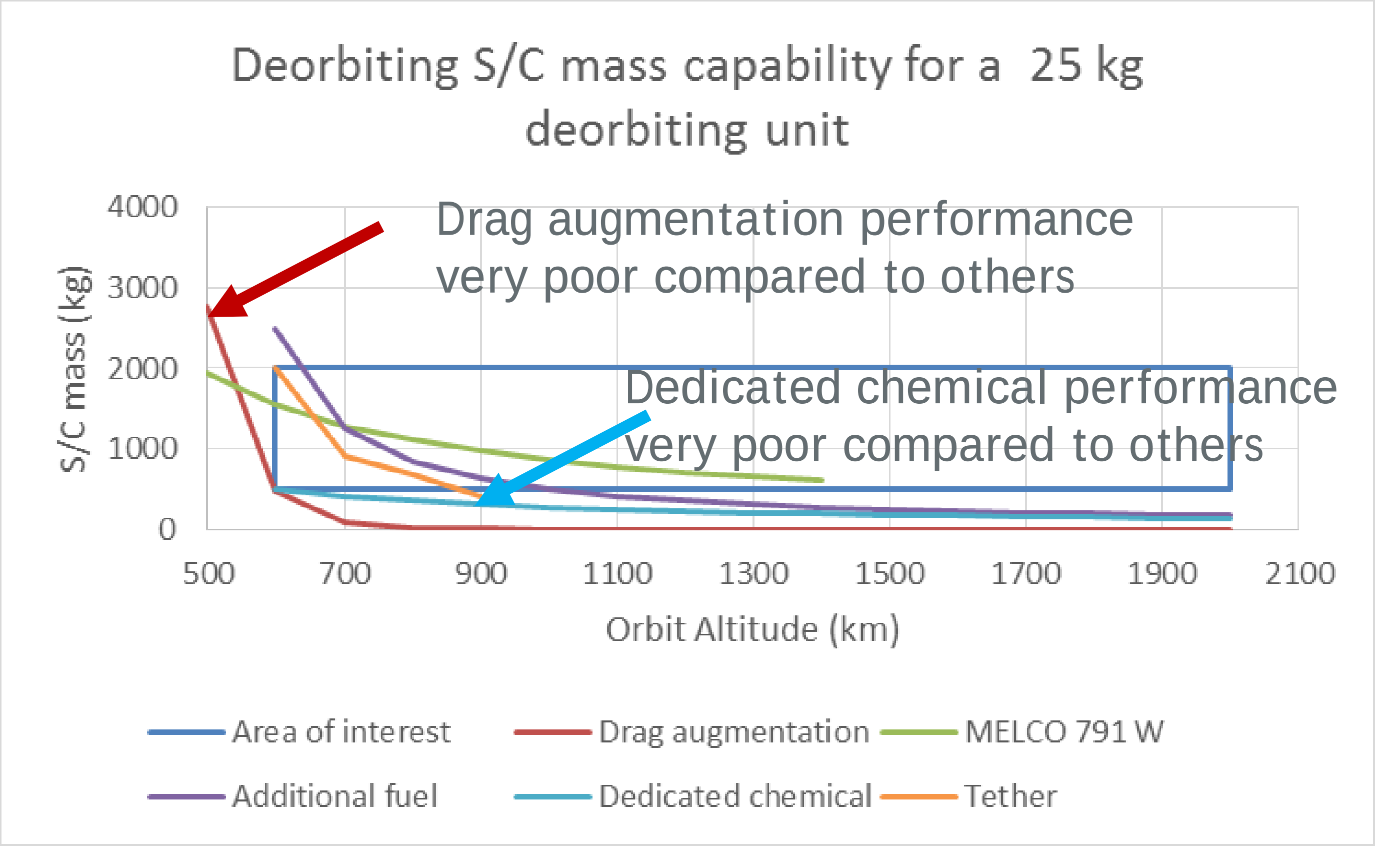
- Assuming equipment mass proportional to tether dimension
- Deorbit in less than 6 months

Electric propulsion

- Based on state of the art propulsion
- Deorbit in 1 year
- 440 power consumption

Chemical propulsion

- Based on SPADES study
- Typical solid booster performance
- Deorbit to 500 km or to 50 km (full deorbit)



Deorbiting S/C mass capability for a 25 kg deorbiting unit

Drag augmentation performance very poor compared to others

Dedicated chemical performance very poor compared to others

Values validated with ESA tool DRAMA v2.0.4

Comparison of performances of a given unit

Drag augmentation

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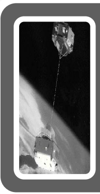

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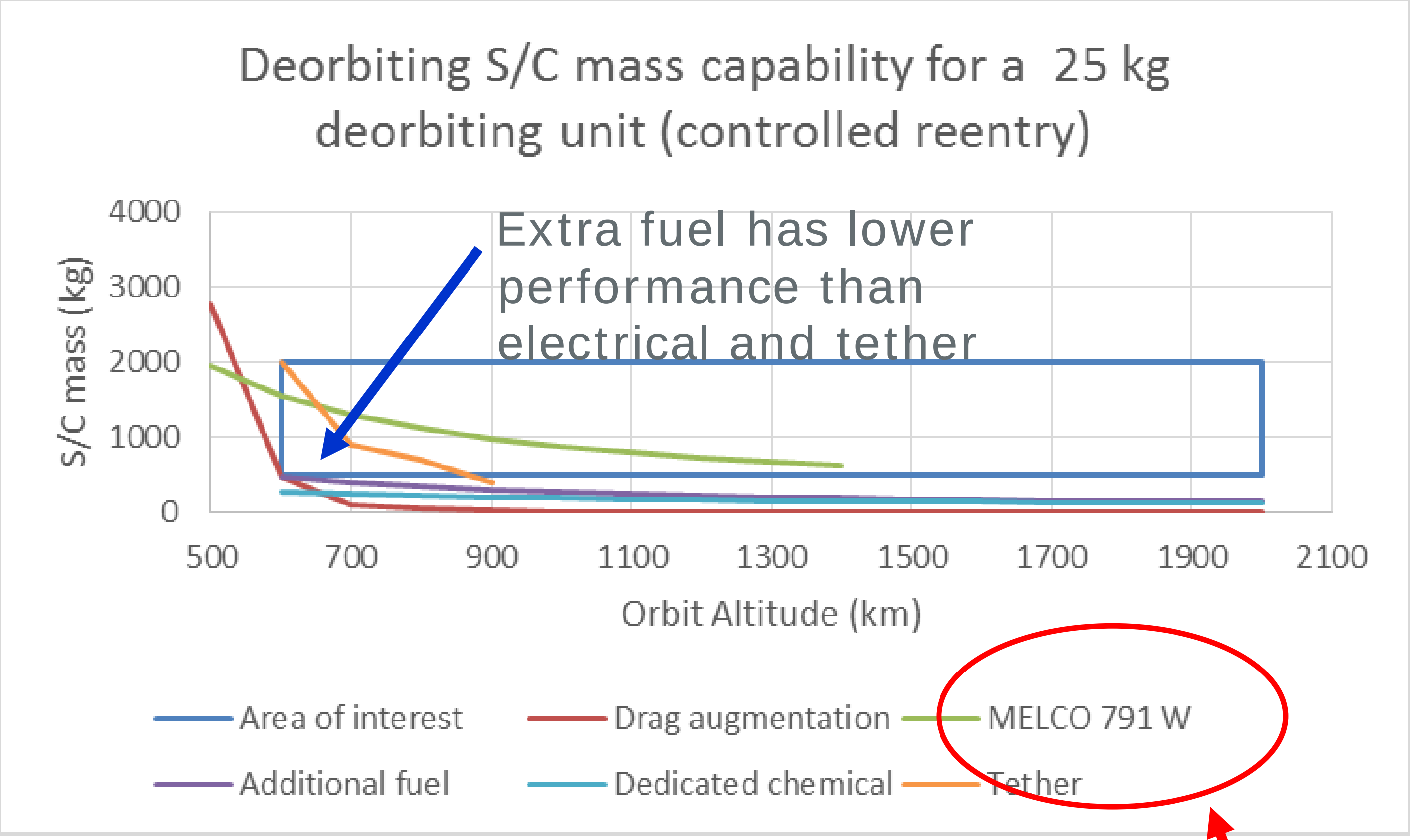


Deorbiting S/C mass capability for a 25 kg deorbiting unit (controlled reentry)

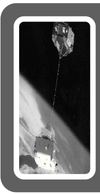
Extra fuel has lower performance than electrical and tether

Extra resources required for electrical, power, ACS

Comparison of performances of a given unit

Drag augmentation

- Assumed 100 g/m2 mass
- Deorbit less than 1 year



Tether

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Electric propulsion

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Chemical propulsion

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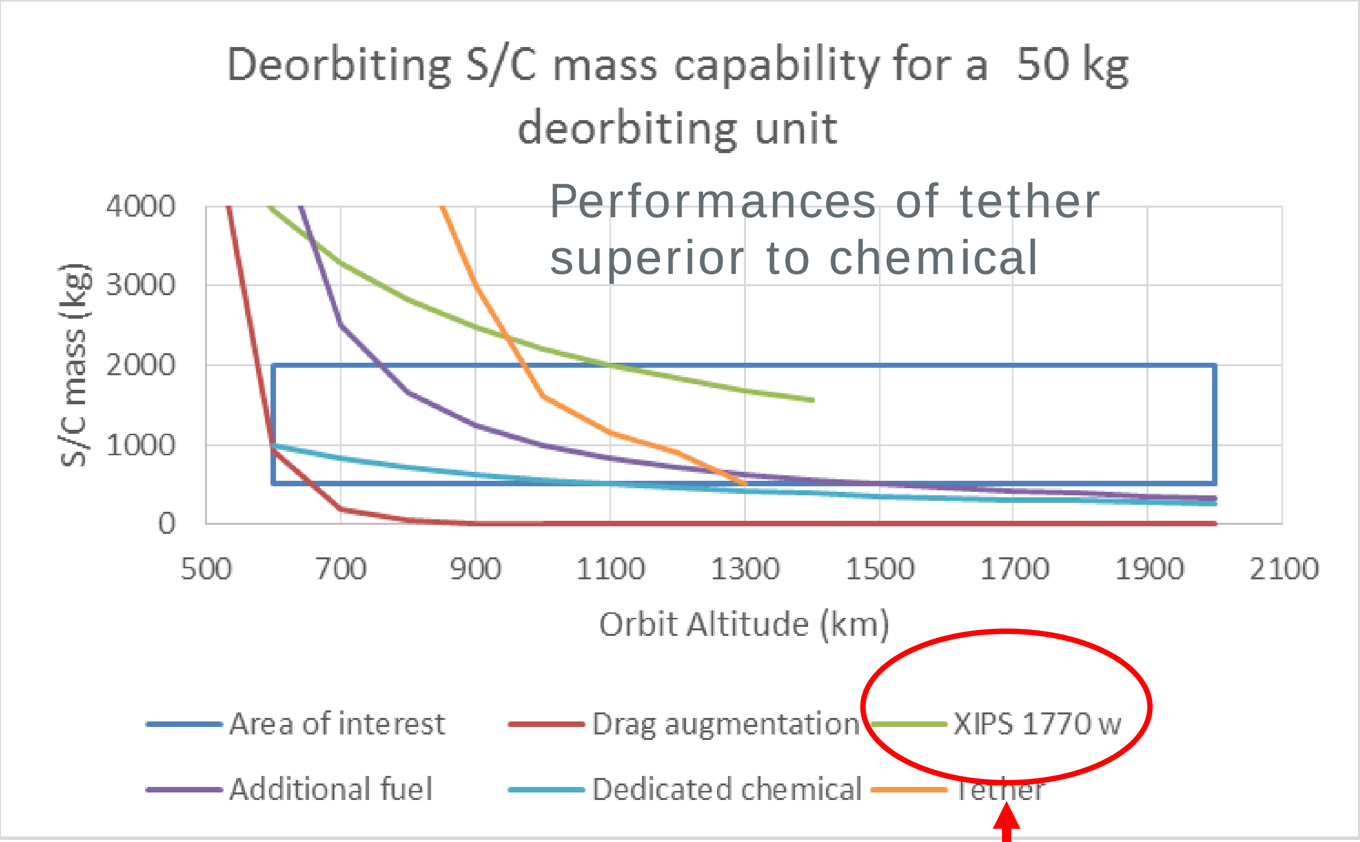


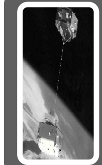
Performances of tether superior to chemical

Unfeasible power demand

Comparison of performances of a given unit

Drag augmentation

- Assumed 100 g/m2 mass
- Deorbit less than 1 year



Tether

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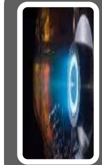

Electric propulsion

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- Deorbit in 1 year
- Dedicated power

Chemical propulsion

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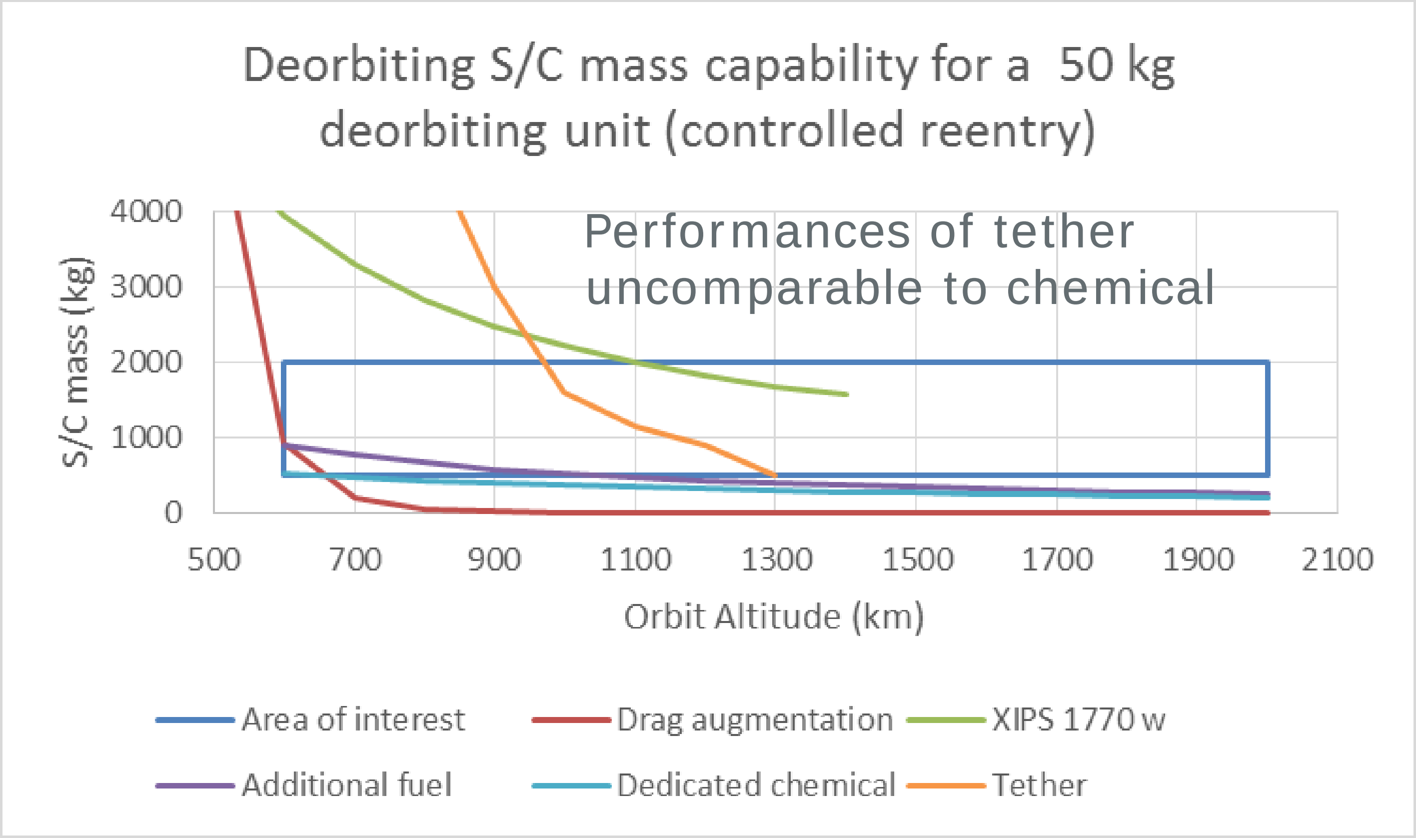


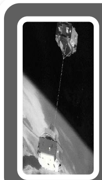
Deorbiting S/C mass capability for a 50 kg deorbiting unit (controlled reentry)

Performances of tether uncomparable to chemical

Comparison of performances of a given unit

Drag augmentation

- Assumed 100 g/m2 mass
- Deorbit less than 1 year



Tether

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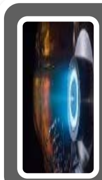

Electric propulsion

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- Deorbit in 1 year
- 440 power consumption

Chemical propulsion

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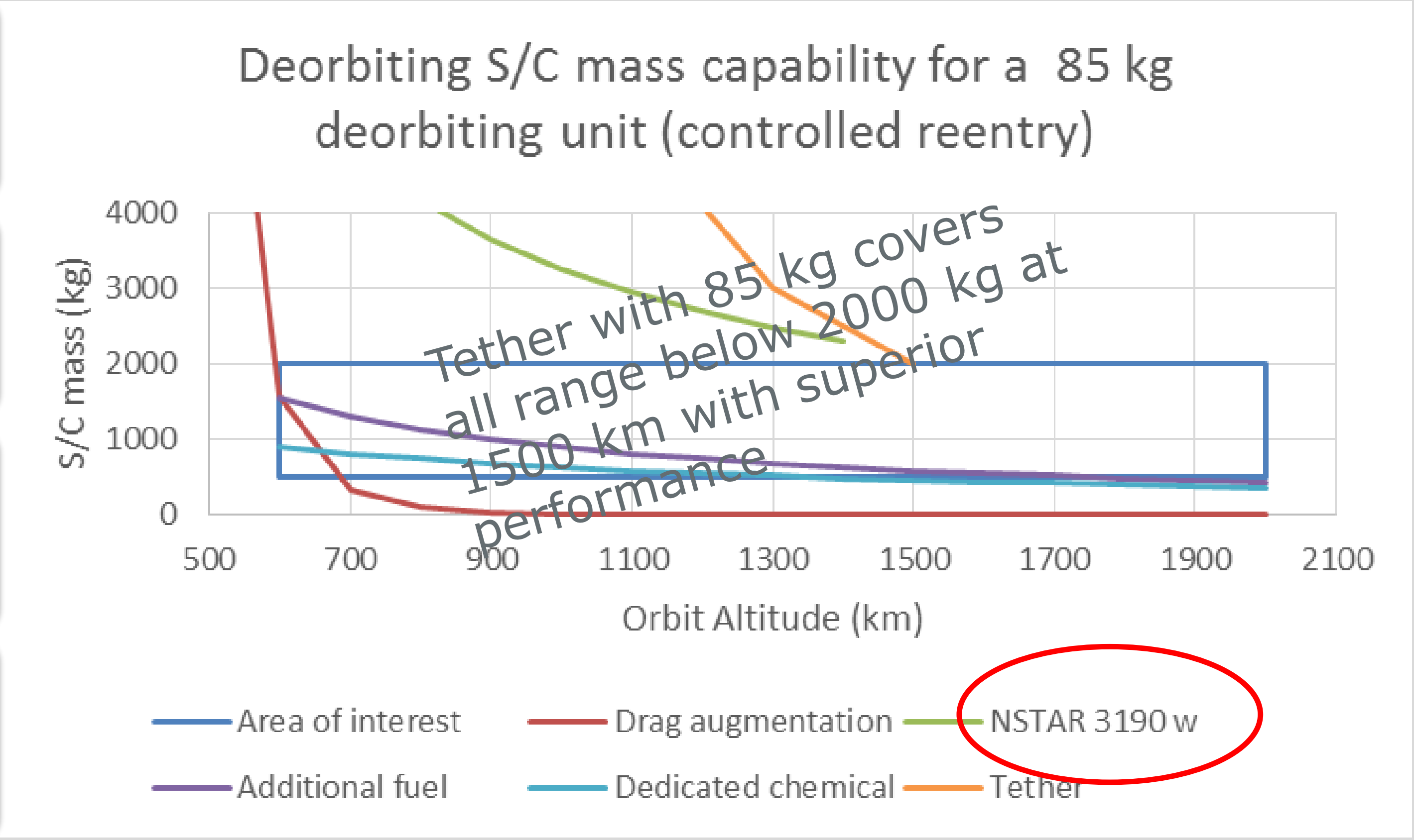

Deorbiting S/C mass capability for a 85 kg deorbiting unit (controlled reentry)

Tether with 85 kg covers all range below 2000 kg at 1500 km with superior performance

Comparison of performances of a given unit

SS mass ratio for bipropellant existing system to lower orbit to 500 km from a 800 km orbit is around 3% of S/C mass

SS mass ratio for bipropellant existing system to full deorbit from a 800 km orbit is around 8% of S/C mass

1000 kg S/C at 800 km requires 100 kg of propellant !

1000 kg S/C at 800 km requires a ≈25 kg tether

Tether for deorbiting is best candidate

Tether technology roadmap for de-orbit

Demo mission

S/C provides attitude for deployment
Release 1 month after launch
Electronics only for HC feeding and activation

Commercial

- Industrialization

Any payload

- Includes attitude control for independent safe deployment

Any orbit

- GTO application

System efficiency

- BTT technology to reduce subsystem mass and complexity

Any mission

- End of mission disposal

……

Conclusions

- BET is more efficient that other technologies in LEO for deorbit
- Prediction of LEO missions envisages a commercial opportunity for BETs
- Environmental friendly technology
- Combination with Design for Demise activities for application to most of missions
- Technology development is needed for specific product although implementation of existing elements with high TRL is possible
- Building a proto-flight deorbiting system is the next logical step

Thanks for your attention

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