

Deployment Mechanism for DESCENT Mission

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Deorbiting Spacecraft using Electrodynamic Tethers mission (DESCENT) is primarily to provide a proof-of-concept of the Electrodynamic Tethers (EDT) system for removal of an end-of-life spacecraft. This paper is to give the concept of the operation and architecture design for the tether deployment mechanism of DESCENT mission. The deployment mechanism is designed to provide the necessary initial separation velocity of our mission requirements, by means of a spring system to produce an impulse force. The compressed spring which is placed in between the two cubes and held together via a burning wire. Once the burn wire is severed, the potential energy stored in the spring would be converted into kinetic energy of the two satellites. The springs had to comply with the geometric constraints of the design and impart the desired velocity. The custom stowage unit has been designed to store the folded tether. The passive braking mechanism is placed in the stowage unit also by means of a spring system. A threaded rod with spring is used to push against the tether to induce the friction force for braking. This braking mechanism is expected to provide a much more consistent performance.

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1. Introduction

Electrodynamic tether (EDT) has been proposed as a promising technology to limit the population of the end-of-life spacecraft due to its lower cost, lighter weight and higher feasibility in Low Earth Orbit (LEO) [1, 2]. To verify the concept of the space tether, many works have been done during the last decades. Among them, TSS-1R and T-REX made an effort to demonstrate the EDT technology, the first one suffered an arcing failure whereas the second successfully demonstrated by use of a hollow cathode [4-6]. However, it will be the first trial of Spindt Array for electrodynamic tethers in the DESCENT mission. DESCENT is designed as two 1U size Cube-Satellites connected by a 100m long bare conducting tape tether to realize the aims of generating current and verifying its effectiveness of deorbiting [3, 7].

The focuses of this study is made on the concept operation and architecture design for the tether separation and braking mechanism of DESCENT mission. The separation mechanism is designed to provide the necessary initial separation velocity of our mission requirements, by means of a spring system to produce an impulse force. The passive braking mechanism is placed in the stowage unit also by means of a spring system. The braking mechanism is similar to that used in the T-Rex. A threaded rod with spring is used to push against the tether to induce the friction force for braking. To verify the feasibility of this design, some preliminary tests were conducted on our ground air bearing platform.

2. DESCENT mission operations

The DESCENT mission focus on demonstrating the feasibility of EDT as a spacecraft deorbiting platform and studying the current generation capability of a 100m long bare conducting tether in Low Earth Orbit. The primary objectives of the mission are as follows: a). Complete a deployment of a 100m long tape Electro-Dynamic Tether (EDT); b). Demonstrate the ability of a bare tape EDT to collect electrons from ambient plasma; c). Demonstrate the ability of a bare tape tether coupled with a Spindt Array to deorbit spacecraft in Low Earth Orbit. The success of these objectives will improve space tether technologies in future space missions ^[3, 7].

The major operations of DESCENT mission are illustrated in Fig. 1. The two Cube-Satellites, mother and daughter, will be launched from the International Space Station (ISS) by NanoRacks LLC. The two Cube-Satellites will be controlled from ground station of York University in Canada. Once the satellites' attitude has been determined and controlled to the desired state, the Cube-Satellites will be separated from each other to realize the tether deployment. After observing the deployment dynamics, the Spindt Array mounted on the daughter will be enabled nominally resulting in Cube-Satellites re-entry within a few days. The entire mission duration is expected within six months.

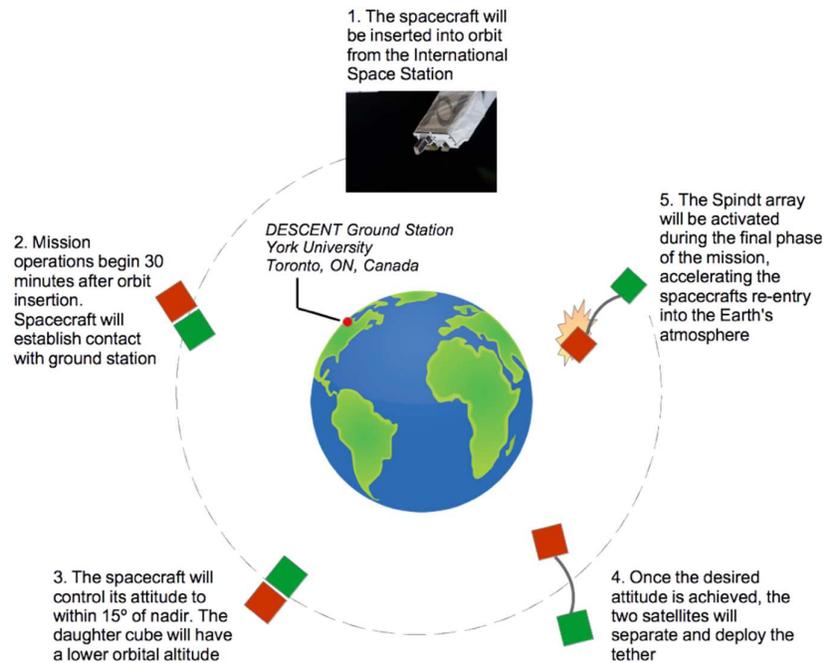


Fig. 1 Concept of DECENT Operations. [3]

The mother satellite is in red, while the daughter satellite is in green.

3. Deployment mechanism design

A passively deployment mechanism has been design to deploy the tether. The deployment system consists of a spring separation system and braking mechanism. The separation is achieved by applying an impulse to the Cube-Satellites to give each cube a pre-determined initial velocity then a brake pad is applied to gradually reduce the relative velocity to zero. One end of tether is fixed on the bottom of tether storage and the other side is fixed on the face of the mother satellite.

Δx is the compressed length. The kinetic energy of the system after separation could be expressed by $E_k = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$, where m_1, v_1 is the mass and velocity of the mother satellite and m_2, v_2 is the mass and velocity of the daughter satellite. The momentum conservation $m_1v_1 = m_2v_2$ and the require initial separation velocity $v_d = v_1 + v_2$.

Then, the relation between the design characteristics of spring and the desired separation velocity is expressed as

$$\frac{m_1m_2}{m_1+m_2}v_d^2 = k\Delta x^2 \quad (1)$$

Thus, one can have the stiffness is not less than,

$$k \geq \frac{m_1m_2}{m_1+m_2} \left(\frac{v_d}{\max(\Delta x)} \right)^2 \quad (2)$$

3.2 Braking mechanism design

The purpose of the braking mechanism is to reduce the relative velocity of the two cubes. The braking mechanism is designed as a spring pad mechanism to passively decrease the relative velocity of the two cubes gradually, see Fig. 3. A spring with known spring constant is attached to a fixed support structure to generate the desired braking force. This braking mechanism is completely passive, thus a constant brake force will be applied over the pre-determined length. The kinetic energy of the system will be dissipate by the friction. The braking force could be adjusted and the distance along which it is applied to satisfy the energy conservation. An advantage of this deployment mechanism is that we can characterize the braking mechanism with

temperature and adjust our initial separation velocity during flight to achieve optimum performance.

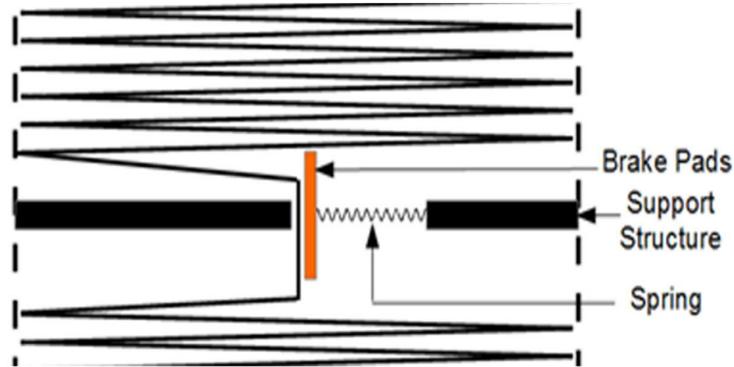


Fig 3 Overview of braking mechanism

The work done by the braking mechanism is $W_{brake} = F_{brake} \cdot s$, where F_{brake} and s are a constant braking force and the braking length respectively. Equating the work done by the braking mechanism to the kinetic energy of the system as expressed:

$$F_{brake} \cdot s = E_k = E_{spring} \quad (3)$$

The braking force and the distance along is applied to satisfy the equation. When choosing the parameter s is advantageous design for a relatively small value so that in the event the braking force is over-estimated, majority of the tether is already freely deployed. However, if the value is too small, then a relatively high force would be required, which is undesirable as it increases the risk of jamming.

3.3 The tether and tether storage

The tether used in the DESCENT mission is 5 mm wide and 35 μ m thick. And the tether is made of a layer of polyester which sandwiched between two thin layers of aluminum to increase the strength. DESCENT will deploy a 100m long aluminum tape tether. The 100m long tether is folded as 'Zig-Zag' type and fixed at the bottom of the tether storage

box by the tether fixed mechanism as shown in Fig.4. The 100 m tether is divided in two parts, 80m and 20m. The first 80m is deployed freely without braking force and the last 20m is set as the braking length with the braking force acting on.

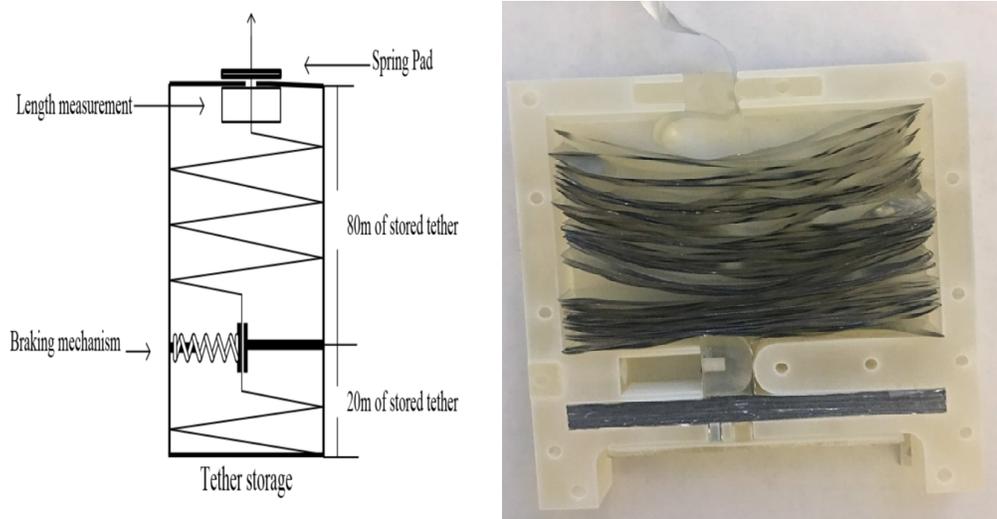


Fig. 4 Tether storage box. Left is the CAD model and the right one is 3-D printed.

3.4 Tensioner System and Burning Wire Cutting System

As shown in Fig. 2, the tensioners are installed on the side wall of the satellites. The function of the tensioner system is to adjust the distance between the two Cube-Satellites. Before separation, two Cube-Satellites are tied together tightly by the tensioner system as the separation spring is fully compressed. The two single wires are placed on the symmetric sides to hold CubeSats together instead of one. This is to reduce the tension in the wire to increase the safety and also to make the system balance. Before separation, the CubeSats are held together by the fiber cables as in Fig. 5. When the system is ready to separate, the burning wire cutting system is powered on through the control command of the OBC. After few minutes, the Dyneema wires are cutting down by the burning wires. Then, the two satellites start separating as shown in Fig.6. As the two satellites separate, the tether will be deployed from the tether storage box.

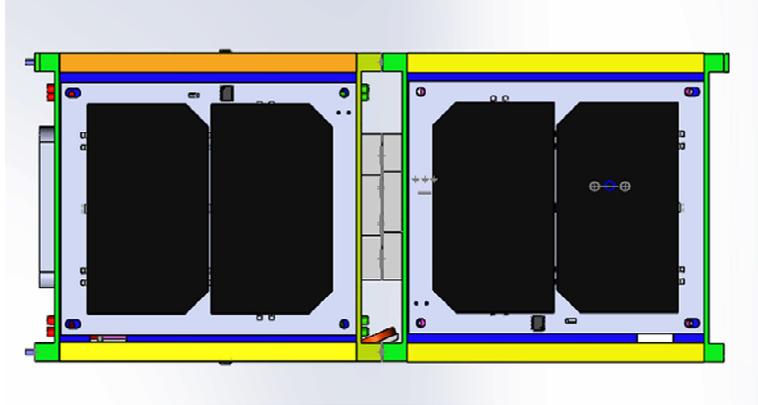


Fig. 5 System with the separation spring fully compressed

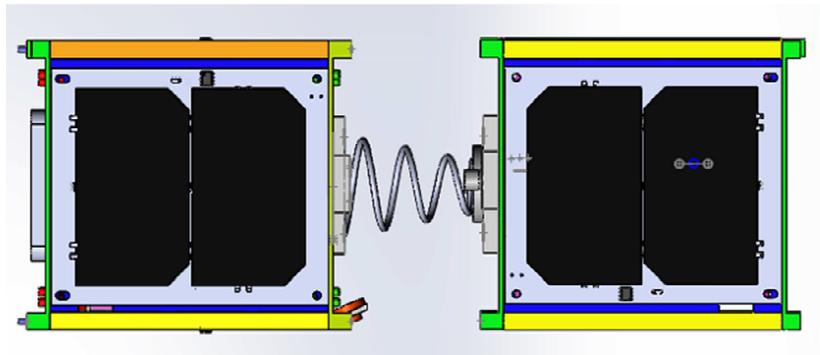


Fig. 6 System after the separation spring released

4. Experiments

To verify our design for deployment mechanism, several tests were setup and carried out on the Ground Air Bearing Platform, see Fig.7. Here, one-direction separation is tested and it could be converted into two-direction separation situation based on directly calculation.

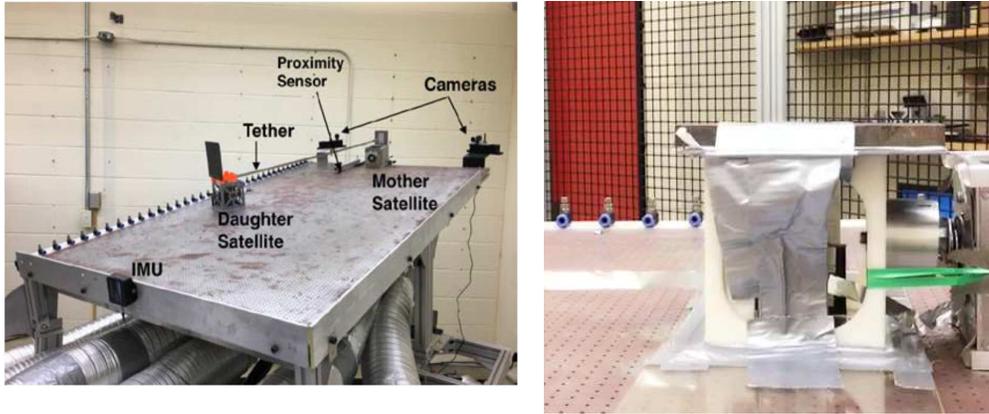


Fig. 7 Ground air bearing platform and Experimental Setup.

The mass of satellite is 1.125kg. The result and parameters measured from the ground test are as follow,

Table 1 Parameters of Ground Test

Satellite's Mass(kg)	1.125
Initial Separation Speed(m/s)	1.2
Brake distance (m)	0.45
Braking force(N)	1.8

Assume the mass two Cube-Satellite for space situation m is 2kg each.

According the conservation of energy, $E_{test} = E_{real}$. Then,

$$0.5mv^2 \Big|_{test} = (0.5mv^2 + 0.5mv^2) \Big|_{real} \quad (4)$$

Substituted the values from Table 1, one could have the absolute velocity of each satellite is $v=0.636\text{m/s}$. The relative initial separation velocity is 1.27m/s . In the real situation, the compression of the braking spring is half than this test. Then the braking distance will increase by 2 times to 0.9m . The results and parameters are show in the Table 2.

Table 2 Parameters of Real Situation

Two Satellites' Mass(kg)	2 (each)
Initial Separation Speed(m/s)	1.27
Braking force(N)	0.9
Brake distance (m)	0.9

5. References

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