

T-Rex: A Japanese Space Tether Experiment

An international team, led by Professor H. A. Fujii at the Kanagawa Institute of Technology/Nihon University, is developing a sub-orbital test of a new type of electrodynamic tether that may lead to a generation of propellantless propulsion systems for low Earth orbit spacecraft.

Electrodynamic tether (EDT) thrusters work by virtue of the force a magnetic field exerts on a wire carrying an electrical current. The force, which acts on any charged particle moving through a magnetic field (including the electrons moving in a current-carrying wire), were concisely expressed by Lorentz in 1895 in an equation that now bears his name. The force acts in a direction perpendicular to both the direction of current flow and the magnetic field vector. Electric motors make use of this force: a wire loop in a magnetic field is made to rotate by the torque the Lorentz Force exerts on it due to an alternating current in the loop times so as to keep the torque acting in the same sense. The motion of the loop is transmitted to a shaft, thus providing work.

Although the working principle of EDT thrusters is not new, its application to space transportation may be significant. In essence, an EDT thruster is just a clever way of getting an electrical current to flow in a long orbiting wire (the tether) so that the Earth's magnetic field will accelerate the wire and, consequently the payload attached to the wire. The direction of current flow in the tether, either toward or away from the Earth along the local vertical, determines whether the magnetic force will raise or lower the orbit.

The bias voltage of a vertically deployed metal tether, which results just from its orbital motion (assumed eastward) through Earth's magnetic field, is positive with respect to the ambient plasma at the top and negative at the bottom. This polarization is due to the action of the Lorentz force on the electrons in the tether. Thus, the "natural" current flow is the result of negative electrons being attracted to the upper end and then returned to the plasma at the lower end. The magnetic force in this case has a component opposite to the direction of motion, and thus leads to a lowering of the orbit and eventually to re-entry. In this "generator" mode of operation the Lorentz Force serves both to drive the current and then to act on the current to decelerate the system.

One of the most important features of tether thrusters is that they use renewable energy sources to drive the electrical current flow in either the orbit-raising or orbit-lowering modes. Sources inherent to Earth orbit are used. To raise the orbit, sunlight can be converted to the electrical energy required to drive the tether current. To lower the orbit, the orbital energy itself (supplied by the Earth-to-orbit launcher when it raises the system into orbit) is the energy source of the tether current via the action of the Lorentz Force.

Electrodynamic tethers can be directly applied to a wide spectrum of uses in space. As a propulsion system, they include satellite de-orbit, transfer of a satellite from one orbit to another, altitude maintenance for large spacecraft such as the International Space Station, and – since it works wherever there is a magnetic field and an ionosphere – planetary exploration missions.

An electrodynamic tether upper stage could be used as an Orbit Transfer Vehicle (OTV) to move payloads within low earth orbit. The OTV would rendezvous with the payload and launch vehicle, grapple the payload and maneuver it to a new orbital altitude or inclination *without the use of boost propellant*. The tug could then lower its orbit to rendezvous with the next payload and repeat the process. Conceivably, such a system could perform several orbital maneuvering assignments without resupply, making it relatively inexpensive to operate.

T-Rex will launch from Uchinoura, Kagoshima, Japan using an S-520 Sounding Rocket. During ascent, and above approximately 100 km in altitude, the 300-meter long tape tether will be deployed at a rate of approximately 8 m/s. Once deployed, the tape tether will serve as an anode, collecting ionospheric electrons. The electrons will be expelled into space by a hollow cathode device, thereby completing the circuit and allowing current to flow. An artist's concept of the mission in flight is shown in the figure.

The first objective of the experiment is to fully deploy the tape tether using a “new” deployment scheme that is actually derived from a very common technique used by firefighters in paying out very long fire hoses. The tape will be folded and stacked into a box with an opening on one end – resembling a tissue box. A spring will eject an endmass attached to the rocket by the tether. As the endmass separates, the tether will be deployed to a total length of 300 meters. The tether is made from aluminum and as it passes through the Earth's magnetic field and ionosphere, it will collect electrons along part of its length. The total amount of current collected will be used to assess the validity of ionospheric current collection models.

The tether generates and forms part of a unique type of electrical circuit, which has been successfully demonstrated in space by flights of the Plasma Motor Generator in 1993 and the Tethered Satellite Systems (TSS-1 and TSS-1R) in 1992 and 1996. Both missions deployed long conducting tethers from orbiting spacecraft and successfully generated a current. The tethered system extracts electrons from the ionospheric plasma at one end (upper or lower, depending upon the deployment direction and intended thrust motion) and then carries them through the tether to the other end, where they are returned to the plasma. The circuit is completed by currents in the plasma.

T-Rex will launch this fall.

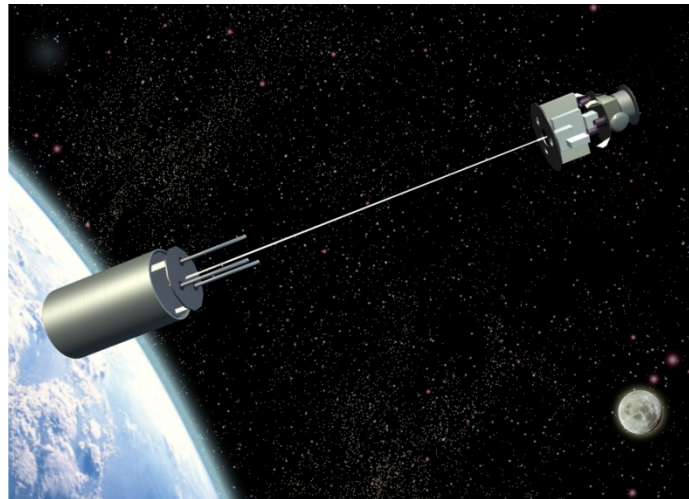


Figure 1 Artist concept of the Japanese T-Rex tether experiment in low Earth orbit.