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# Chapter 23

# TSS 1—The "Tethered" Satellite Deployed from the Space Shuttle*

**Luigi Bussolino**†

## Abstract

The "tethered" satellite was an idea of an Italian genius, Prof. Giuseppe Colombo from Padoa University and Harvard Smithsonian Center for Astrophysics in Massachusetts, who was for many years a scientific consultant for NASA, providing the calculations of the orbital periods and movements of the planet Mercury. Prof. Colombo proposed to NASA, as well as to the Italian Space Agency (Agenzia Spaziale Italiana, or ASI), the mission with a satellite appended to the Shuttle via a 20-km cable length for demonstrating in space some physics laws, one of them concerning the production of electrical current in a conducting wire passing through Earth's magnetic field. An agreement between NASA and ASI was then reached, and the satellite with onboard experiments was designed by Aeritalia company, while the mechanisms of release/deployment onboard the Shuttle were designed by Martin Marietta of the U.S. The sophisticated mission started with the "electrodynamics experiment" in July 1992 and, due to an interface problem, was repeated in 1996 when a short circuit in the cable caused the loss of satellite. The results of the mission, even if shorter than expected, were appealing and important to support other ideas, such as electrical provision for

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space stations as well as space elevators, even if the mission was not more repeated.

This chapter is based on the author's experience.

## Background

The concept of a "tethered" satellite, i.e., a satellite connected by a cable to the Shuttle, was born in the mind of Italian genius Prof. Giuseppe Colombo of Padoa University, a well-known expert in the field of celestial mechanics, who was also working for the Harvard Smithsonian Center in Cambridge, Massachusetts.

Prof. Colombo obtained great success in NASA for his studies on Mercury and the mission orbits of the American space probe Mariner 10, launched toward that planet, the nearest to the Sun in our solar system. See Figure 23–1.

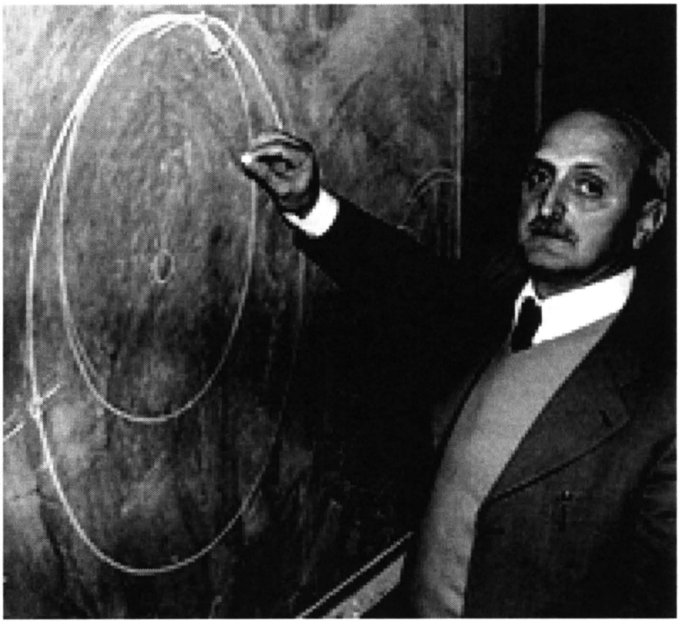

**Figure 23–1**: Prof. Giuseppe Colombo teaching at the university.

The original idea really started from another Italian professor, Prof. Mario Grossi, a radio-physicist at the Harvard Smithsonian Center for Astrophysics, who proposed to NASA in 1972 the development of a big spatial antenna for very low frequency communications. This antenna consisted of a conducting aluminum cable of a few millimeters diameter but as long as 20 to 100 km.

Prof. Grossi was able to involve his Padoa colleague in the research, but Prof. Colombo developed the concept in a different manner and convinced NASA and the Italian National Research Council (Consiglio Nazionale delle Ricerche, or CNR), that was managing the National Space Plan, the initial embryon from which was born the Italian Space Agency, to develop it. In 1984 the two agencies signed in Rome a memorandum of understanding for starting a bilateral program. NASA would be responsible for the launch and the global system, whose part onboard the Shuttle, the release mechanisms and cable retrieval, was under the responsibility of American company Martin Marietta in Denver, Colorado, while the satellite part, wire appended and with all the scientific experiment onboard, was under Italian responsibility (Aeritalia in Turin), see Figure 23–2.

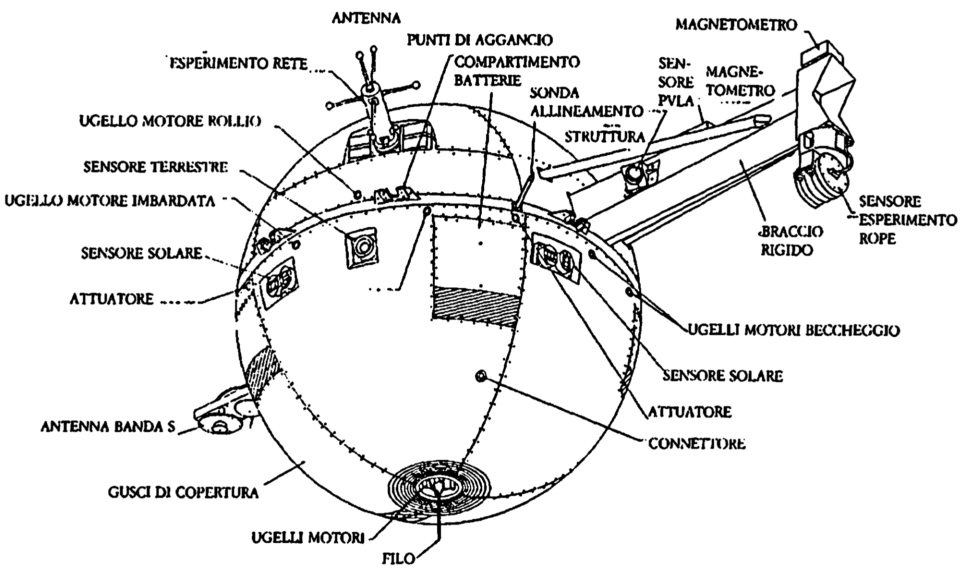


**Figure 23–2**: Figure of the overall satellite with explanations.

Prof. Colombo was also able to convince many key persons, such as James M. Beggs, the NASA Administrator at the time* and the American scientist Nobie Stone, and in Italy Prof. Luciano Guerriero, CNR National Space Plan Director, and Prof. Ernesto Vallerani, Aeritalia Space Systems Group Director, showing that it is possible to descend from the Space Shuttle a satellite appended to a cable of 20-km length and more to 100 km, for studying and analyzing Earth's atmosphere between 100 and 200 km height.

* James M. Beggs served as NASA Administrator from 10 July 1981 until 4 December 1985.

This is not possible to perform with rockets that will return to Earth with a ballistic trajectory, because the orbit is too low for allowing flights longer than some days or passing through these layers only in the atmospheric reentry. The Shuttle orbit, at about 300 km of height, was the best for this kind of experimental research. Moreover, the wire and the related circuitry should act as a spire passing in the terrestrial magnetic field, then generating induced current and, then, charges moving in the wire (electro-dynamic mission).

In 1985 a bilateral group of scientists was formed with the specific job of proposing experiments to be carried out on this Italian satellite. Coordinators of this investigative working group (IWG) were Prof. Marino Dobrowolny of the CNR Institute of Physics for Interplanetary Space and Prof. Nobie Stone for the American side.

This group selected, then, twelve experiments to be carried by the satellite, among them Dobrowolny's RETE (Research on Electrodynamic Tether Effects), Mariani's TEMAG (Tether Magnetic Field Experiment) and Stone's ROPE (Research on Orbital Plasma Electrodynamics), that had to measure the interactive relationships between satellite itself and plasma surrounding the satellite (RETE and the ROPE) and the magnetic environment around satellite (TEMAG). The satellite then received two arms: one with ROPE's sensor and the magnetometer and the other the S-band antenna.

Other scientific experiments were concerned with the basic experiment, the electrodynamic one of Prof. Bonifazi, represented by the "core equipment" on-board the satellite as well as other components on the Shuttle cargo bay, that had to make an electrical circuit between Earth and satellite (from one side it was represented by the conductive wire and from the other side from the electrons flux emitted by an electronic gun). See Figure 23–3.

The first mission of the Tethered Satellite System (TSS) was, then, the electrodynamic one, during which the experiment was the production of current flowing through the cable and then measured from the onboard instrumentation. The cable (not supposed to experience any tension load, even if the satellite and Shuttle would fly into two different orbits with the height difference of 20 km equivalent to the wire length itself) was designed with a diameter of 2.54 mm, with a core of Nomex surrounded by ten copper wires of 0.16 mm in which the current had to flow and a Kevlar sheath, all externally covered by a Nomex skirt, see Figure 23–3. The whole cable of 20 km was not exceeding 8 kg mass.

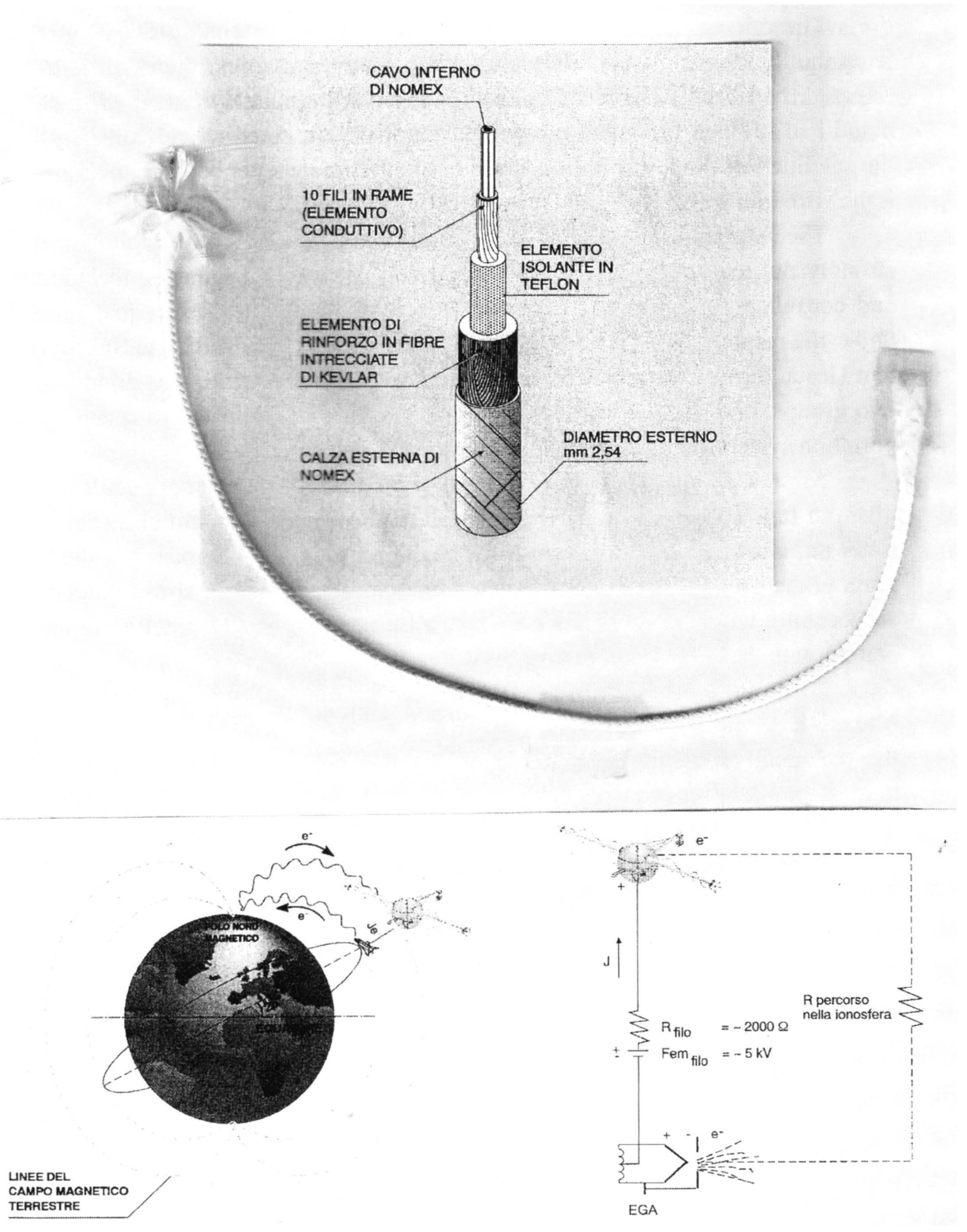


**Figure 23–3**: Top—Sample of tethered satellite cable with section and overall scheme. Bottom—Tethered satellite mission traversing Earth's magnetic field.

The release mechanisms were complex: a tower extending for 12 meters from the Shuttle cargo-bay with, on top, a canister containing the satellite to be released, had been designed. Once the tower was completely extended, a command had to open the mechanical interfaces between satellite and canister, and the satellite left the tower with a speed of about 2 meters per second, taking with it the wire into the free space.

The satellite, designed by Alenia Spazio in Turin, had a difficult start that strongly put to use the capabilities of a great number of engineers, technicians and consultants required to reinforce the scientific satellites group just formed under the responsibility of Dr. Bevilacqua. In fact, in 1982–1983, the Space System Group, now under the full responsibility of Prof. Vallerani, was divided into two groups: one for scientific satellites and the second dedicated to space transportation systems under Mr. Piantella's responsibility.

After a series of changes, the program management responsibility was given to Ing. Tornani, who performed well, and overcame the initial difficulties. Later on, after leaving the program for health reasons, Ing. Tornani put the program in the hands of Ing. Bruno Strim, who completed it, as he already had done successfully with the Hipparcos satellite, a European scientific satellite in cooperation with the French Matra company.

From the ASI side, the program was managed by Ing. Gianfranco Manarini, an open-minded man, keen to collaborate with industry in trouble for the technical problems encountered during this complex satellite design. The biggest problem was the understanding of the basic dynamics of the body appended to the cable to be extended into space and then returned to the Shuttle, as a dog when the owner pulls the lead. Many months were necessary to understand the physics and to prepare the simulations for the behavior of the satellite and then develop the detailed design. If remember correctly, a great amount of help came from Prof. Bergamaschi of Padoa University, who was the sole man understanding the fundamental problems of yo-yo movement (but not so similar) when the satellite was recalled.

Finally, the satellite came as a sphere of 1.6-m diameter and of about 500-kg mass, divided into three parts: the superior compartment had the scientific instrumentation (around 70 kg) and the lower compartment was also divided into two parts. See Figure 23–4.

The upper part of this compartment, near to the maximum circumference, was occupied by the onboard propulsion system that had to push the satellite during the releasing phase (and in the opposite direction but with completely different laws during the recovery phase). In addition, the onboard propulsion system had to contribute to the general stabilization and the pointing attitude control by means of various sensors. In the lower part of the compartment there were the service module with onboard subsystems from the electrical power supply, and the attitude control computer, the data handler for elaborating and transmitting the scientific data as well as the housekeeping.

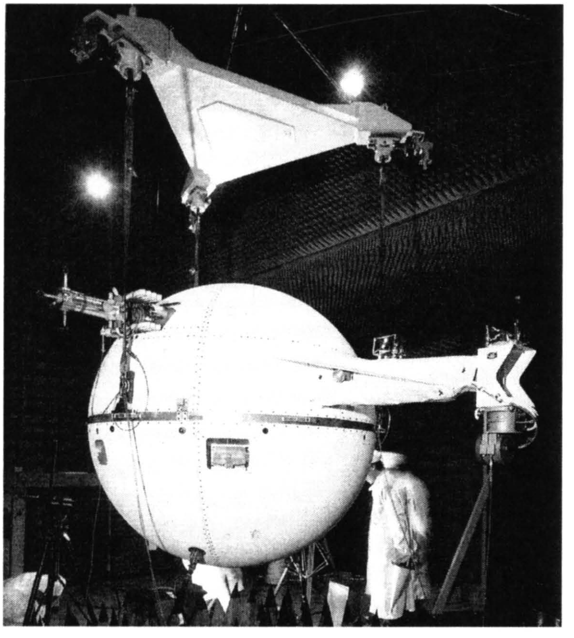

**Figure 23–4:** Tethered satellite in acoustic test bay.

Another problem came also from the white paint selected for its low thermo-optical properties to lower the solar heat absorption, to isolate the inner part of the satellite, and in the meantime have a great surface electrical conduction for allowing the reception and distribution of the electrical charges to be collected. This paint was initially provided from NASA through GSFC (Goddard Space Flight Center). But later on, one month before launch, NASA imposed the paint produced by MSFC (Marshall Space Flight Center) that had better performance (compelling Aeritalia to paint new structural elements and substitute them with the parts already installed on the satellite).

Another challenge solved by Italian engineers was the design of the electronic gun, for Aeritalia's responsibility "core equipment" preparation, made by Proel company in Florence, consisting of two electron generators (one as spare) of 1 ampere power. The basic idea was that the electrons would go to the Earth pole and then return to the satellite and, throughout the conductive cable, reach the generator thus closing the circuit. Laben company in Milan had to design and develop the data handler for the satellite-Earth data exchange.

## The First Mission

The satellite performed a series of tests both in Turin, Aeritalia premises, and the final thermal vacuum test in Germany, Ottobrunn IABG premises, and then was finally consigned to ASI. Later on, the satellite was delivered to NASA, and in June 1992 NASA started the online integration activities with the Shuttle and the other mission payloads.

At the end of July, after the last controls, and charging of the tethered primary batteries, that would provide power just for forty days, the Space Shuttle was ready to be launched on 31 July 1992. The first Italian astronaut, Ing. Franco Malerba, was onboard among the crew: he was able to fly due to the bilateral NASA/ASI agreement, after having overcome a series of typical Italian troubles that lasted at least ten years after his participation in the Italian astronaut selection process.

The Shuttle mission was also foreseeing the on-orbit deployment of the European platform "Eureca"(standing for European Retrievable Carrier) left in space with a series of scientific instruments and to be recovered within a year and carried back to ground always from the Shuttle. Aeritalia was responsible for the carbon fiber structure design and manufacturing for this platform.

The tethered satellite mission was not as successful as expected: the satellite was released only for 256 m (on ground it was discovered that this came from a protrusion of a bolt in the main structure of the release mechanism, I believe, not well controlled by Martin Marietta, that, causing friction on the cable, was not allowing the correct release movement, in spite of the functional test done on the satellite). From the electrodynamic standpoint, the first mission was positive, notwithstanding the limited length of released wire, because a current of a few milliamperes was generated.

NASA, after the necessary ground investigations, understood the mistake (as usual the controls on the foreign partners were too severe in relationship with the control of American suppliers). As an example, I remind that to the various tethered reviews many NASA employees and NASA subcontractors that were also their consultants (and this not only for the tethered project but also for other programs). Those people were controlling all our reports from all standpoints, from the technical to the "safety" ones, and were not hesitating to issue any type of comment, compelling us to remake or deepen works and analyses on questions that were not convincing them well enough, while they were less severe in front of American companies.

I believe that from the manufacturing drawings, to be controlled for giving the authorization to proceed, the tethered problem was already evident, as well as later on from the functional tests, if carefully conducted. For this reason NASA was allowing a reflight mission of the satellite that had to be slightly modified to proceed.

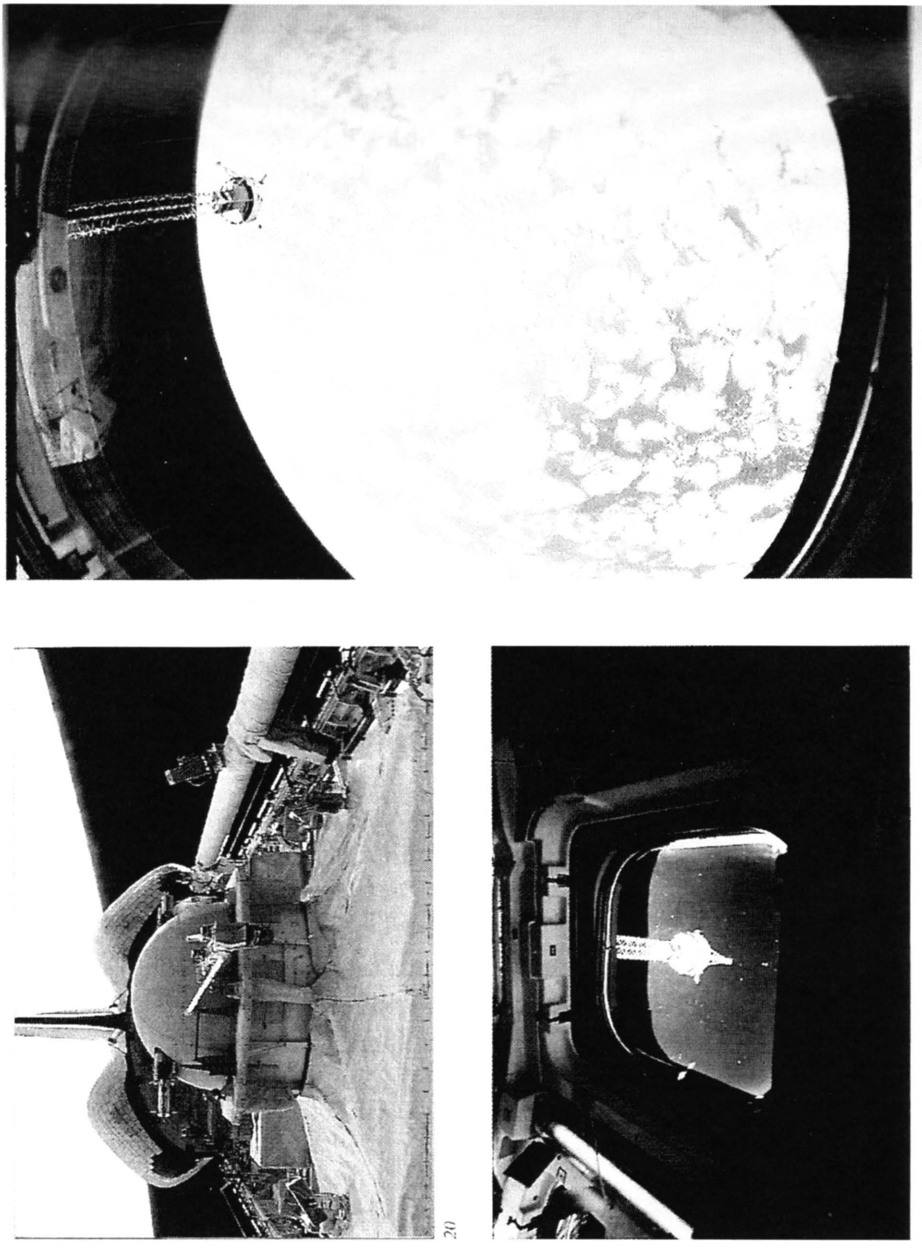

**Figure 23–5**: Three views of tethered satellite in the cargo bay. On top of the deployed tower and seen by the crew of the Space Shuttle.

## The Second Mission (Reflight Mission)

With the modifications conducted by Aeritalia to the attitude control and those by Martin Marietta to the release/retrieval mechanism, we arrive to 1996, when the satellite came back to the United States for the final integration with the Shuttle.

In this event, in the crew of the STS-75 mission, was included the Italian astronaut Umberto Guidoni, who four years before acted as backup to Mr. Malerba in the previous mission. In this mission crew, there was another Italian, Mr. Maurizio Cheli, test pilot in Aeritalia, selected as astronaut in the ESA group.

The mission was going well at first: once in orbit, the tower with the satellite on top reached its maximum extension, and the satellite was carefully released step by step until 19.9 km of length but, then, the cable broke off and the satellite flew into deep space, with much dismay of the crew as well as of the public following the event.

The explanation was not simple, but the records were showing the current flowing in the wire without any problem until a certain point in which a probable defect in the wire created an increase of resistance and, then, a short circuit that burned out the cable, breaking it. (NASA was not thinking to use a new cable in respect to the "old" one already flown four years before, neither was controlled before or later with a simple continuity test). The satellite was visible for a long time, mainly because of the length of the cable, reflecting the sunlight, and reentered the atmosphere three days later, destroying itself.

The short satellite operating life in this reflight mission allowed many verifications on main scientific questions at the base of the mission. In any case, the costs of the mission, of many hundred million dollars, even if subdivided between NASA and ASI, were high enough for not proceeding on with any other kind of mission, including more complex ones, already planned.

From a preliminary estimate, the first flight cost was around $250 million subdivided between NASA and ASI (the satellite value was around $75–80 million and the Proel electron guns $25–30 million, in addition to ground tests and the launch preparation $25–30 million), while the second flight cost another $150 million, perhaps not a cheap price for verifying some theoretical physics principles.

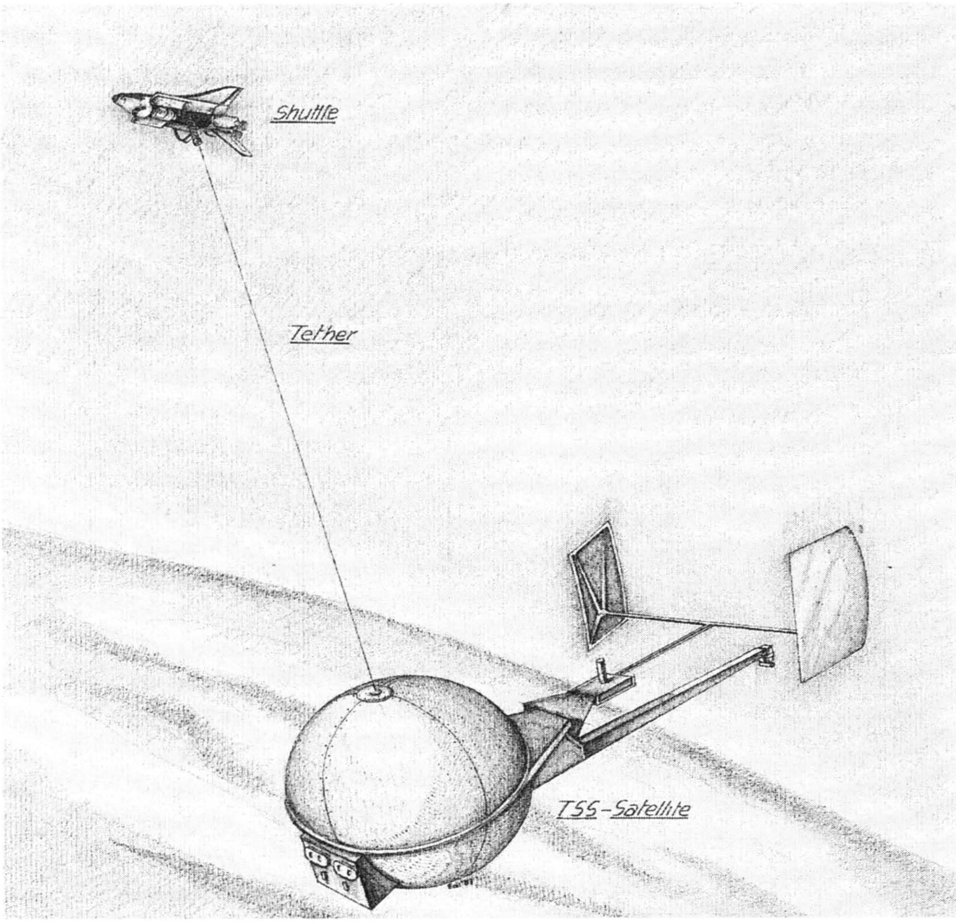


**Figure 23–6**: The atmospheric mission, artist's view.
Credit: Aeritalia brochure 1987.

## The Follow On

The theoretical studies and the results obtained demonstrated the feasibility of a "space lift" of gravitational type, i.e., a system with a platform capable to move along a cable and reach different heights for organizing experiments at different microgravitational values, as well as supply power through wire to a future space station orbiting around Earth.

For many years the concept of a tethered satellite was developed in the United States by Prof. Robert Forward and Prof. Robert Hoyt, who founded the company "Tethered Unlimited Inc." in various applications, one among which considered the possibility to deliver payloads from LEO to cislunar orbits and more (MERITT project, standing for MARS Earth Rapid Interplanetary Tether Transport) all based on tethered cables.

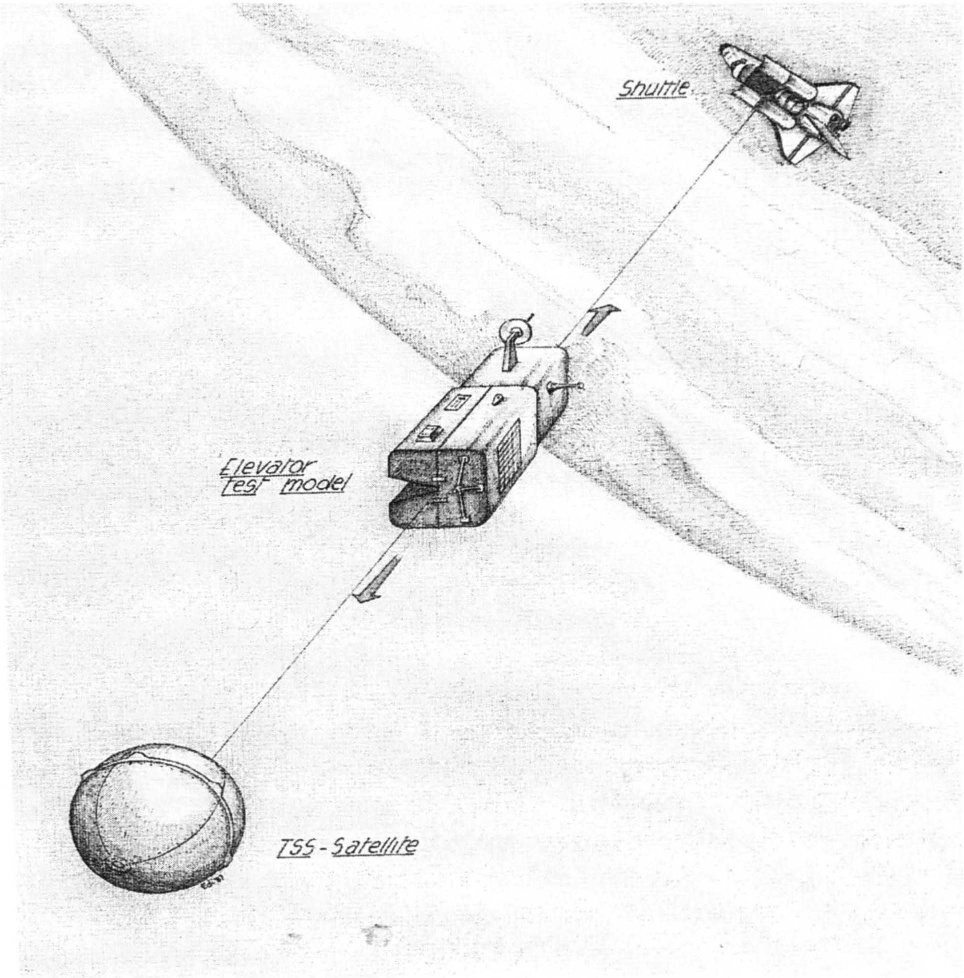


**Figure 23–7:** "Elevator" mission scheme, artist's impression.
Credit: Aeritalia brochure 1987.

Also, Dr. Les Johnson, a scientist at Marshall Space Flight Center, was considering for a long time the potentiality of a tether as propulsion system and organized some experiments called "ProSEDS" for Propulsive Small Expendable Deployer System, i.e., a system for tether propulsion installed on top of a Delta II launcher.

As manager responsible for the advanced study group in Alenia since 1992, I was trying to not lose this specific experience in our company, and I developed some of these studies with small internal funds. Specifically, I supported for some years the EDOARD project standing for Electro-dynamic De-Orbiting and Re-entry Device, i.e., a tethered system for deorbiting at end of life or in case of failure of a satellite, from an idea of Prof. Luciano Iess and Claudio Bruno of the Space Department in Engineering, Rome University "La Sapienza" and developed by Turin Alenia Space.

Surely it would be necessary to the open mind and admirable fantasy of a person such as was Prof. Colombo, who any time coming to Aeritalia entertained with his jokes but also whipped us young engineers with a lot of very complicated physical problems, showing in any case an advanced vision of space applications.

In Padoa University, CISAS (Centre of Studies and Activities for Space) was named by him and, in 1994, ten years after his death, the university organized an international congress in which the "ideas for space researches after 2000" were discussed, starting from the perspectives opened by him.

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