National Aeronautics and Space Administration

NASA Case Study *MSFC-CS1007-1*
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Tethered Space Satellite-1 (TSS-1): Wound About a Bolt

In the early 1990's US and Italian scientists collaborated to study the electrodynamics on a long tether between two satellites as it moved through the electrically charged portion of Earth's atmosphere called the ionosphere. Potential uses for the electrical current induced in the long wire include power and thrust generation for a satellite, momentum exchange, artificial gravity, deployment of sensors or antennas, and gravity-gradient stabilization.

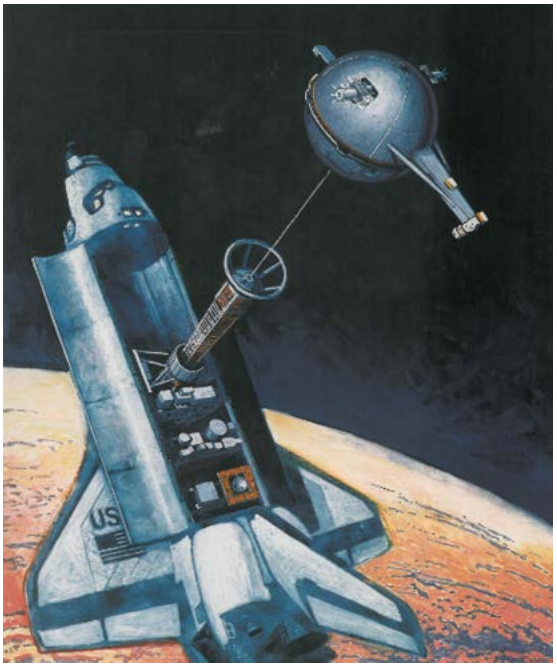
Figure 1 *Artist rendition of the Tethered Space Satellite (NASA)*

The Tethered Space Satellite (TSS) was a first-of-its-kind experiment with long tethers in space. It consisted of a satellite with science experiments attached to a 12.5 mile long, very thin (0.10 inch diameter) copper wire assembly wound around a spool in the deployer reel mechanism. The whole mechanism sits on a pallet that is installed into the Shuttle bay. At an altitude of 160 nautical miles above earth, the satellite would be deployed from the Shuttle bay by raising it on a boom facing away from Earth. Once cleared of the bay, the deployer mechanism would slowly feed out the 12-plus miles of tether. Scientific data would be collected throughout the operation, after which the satellite would be reeled back in.

A receiver spool to catch the 12.5 mile tether as it was being unwound by the deployer reel mechanism was set up to do the system-level test of deployer real mechanism prior to installing the loaded pallet into the Shuttle bay. The system level tests were required before the pallet could be installed into the Space Shuttle cargo bay. A few months before flight, the system level tests, including unreeling and reeling the tether, were completed at Kennedy Space Center (KSC) and the TSS payload was installed onto the Spacelab pallet. Some of this testing equipment was then shipped back to the contractor, Martin Marietta. Integration with the Shuttle began.

Systems-level load analyses, which cannot be run until all information about each payload is finalized, was run in parallel with the physical integration of the hardware into the Shuttle payload bay. An analysis, called Coupled loads analysis, incorporates any updates to the model due to system level tests of all the different payloads, and any changes that were found during integration. Engineering analysis examines the worst case scenarios for the loads the hardware will see. The two times during the mission where the dynamic loads are the worst were 1) the first 10-second portion of Shuttle lift off, and 2) a 2-second time during landing when the landing gears hit the ground. The coupled loads analysis using the final verification loads showed that a single bolt attaching the deployer reel mechanism to the support structure had a "negative margin" – which is an indication that it might fail – during touch down. Hardware certification rules do not allow for hardware to fly with negative margins. A structural failure of one payload could have serious or catastrophic consequences to other payloads, or may significantly damage the Orbiter. The issue had to be resolved before the flight.

Engineering analysis contains conservatism, so there was an option to waive the margin requirement and fly the experiment as is. Minor design changes might be possible in the payload bay prior to launch. Major design changes that required the spooling test for validation or required the pallet be removed would cause TSS not to be ready for the Shuttle launch.

One option was to replace the bolt with a high strength bolt of the same size. Changing the bolt could be done with the hardware as is. Unfortunately, high strength bolts are a long-lead item in the normal procurement processes. TSS-1 wouldn't be ready for launch in time. Despite searching, there wasn't another bolt at NASA that could be used.

A third option proposed by the design team was to replace the current fastener with a shear wedge. A shear wedge is a C-shaped clamp that provides a different load path between two plates. With a shear wedge, analysis showed a positive margin for the joint, and it could be done on schedule. The hole that the fastener was inserted into was a through hole, giving some room to use a longer bolt than originally planned. After verifying the fit of the bolt in the hole with the designers, who double-checked their drawings, the change was considered minor, and everything looked ok.

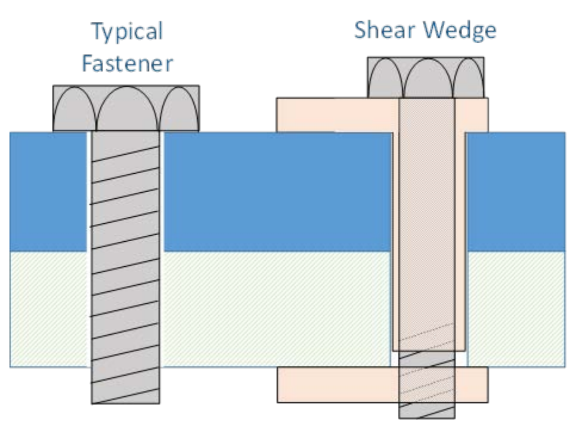

Figure 2 Fastener configurations for TSS-1 (a) nominal fastener in joint assembly, (b) modified joint assembly

You Make the Call

Should the margin be waived, the shear wedge be installed, or should you wait for a new bolt?

The Rest of the Story

The first TSS electrodynamics mission was launched aboard the Space Shuttle Atlantis (STS-46) on July 31, 1992, as a joint mission between the United States and Italy. Operations were nominal. With the Shuttle in orbit at an altitude of 300 km (160 nautical miles), TSS-1 deployment began. The boom with the satellite was extended, raising the satellite and tether "upward" (toward space). The tether began deploying at a rate of 5.9 inches (15 cm) per minute. At 78 meters the tether stuck. The snag was resolved and the tethered continued until it reached a length of 256 meters, where it stuck again. The satellite reached a maximum distance of about 260 m (854 feet) out of the planned 20,500 meters (12.5 miles). The problem was found to be a protruding bolt that jammed the deployment mechanism and prevented deployment to the full extension. The bolt in question was the late-stage modification to the reel system.

Figure 3 Close up view of TSS-1 from Space Shuttle Atlantis bay

Although TSS-1 did not deploy properly, and the voltage and current reached using the short tether length were too low for most of the experiments to run, there was still some science data retrieved. Low-voltage measurements were made, and variations of tether-induced forces and currents were measured. New information was also gathered on the "return-tether" current.

Most significantly, TSS-1 demonstrated the feasibility of deploying the satellite to long distances, settled several short deployment dynamics issues, and reduced safety concerns. TSS-1 conclusively showed that the basic concept of long gravity-gradient-stabilized tethers is sound.

The TSS mission was reflown in Feb. 22, 1996 on STS-75 on the Space Shuttle Columbia as TSS-1R. TSS-1R successfully deployed to 19.6 km (12.3 miles) before the tether suddenly broke and the satellite sprung to a higher orbit. Despite being disconnected from the Shuttle, flight control at Johnson Space Center (JSC) and Marshall Space Flight Center (MSFC) were able to restart some experiments, which were able to continue for 3 days, until the satellite batteries died. While TSS-1R also failed to complete its mission, both TSS-1 and TSS-1R provided invaluable data on long tethers in space.