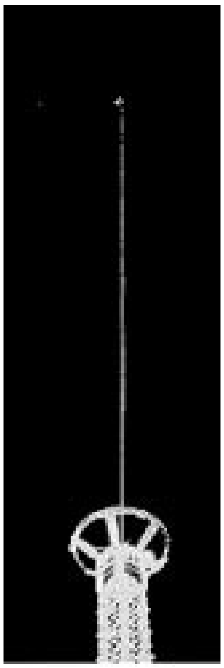
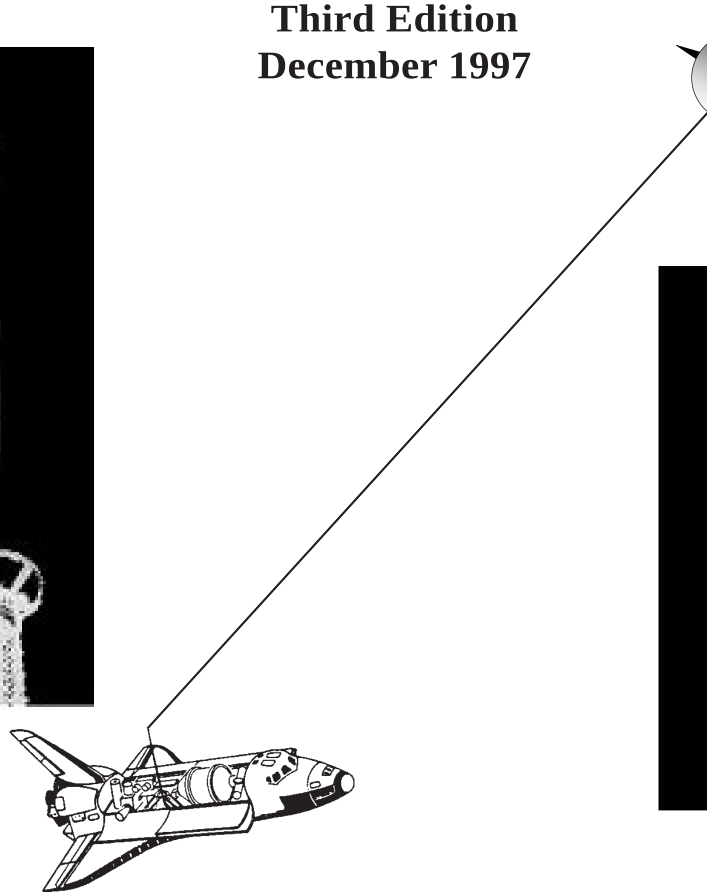
Tethers In Space Handbook

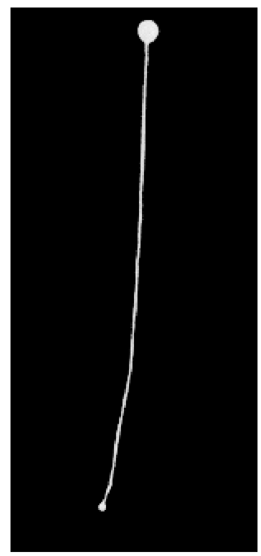
Third Edition
December 1997

TSS-1





SEDS-2



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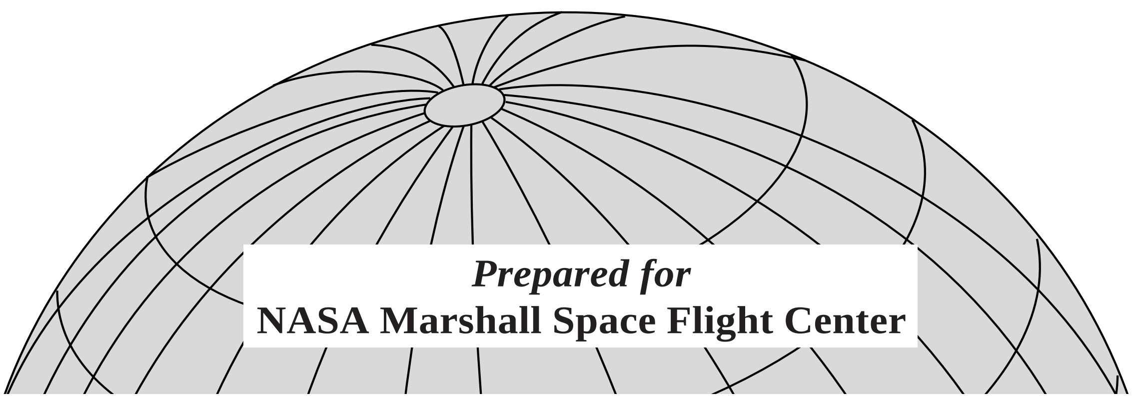

Prepared for
NASA Marshall Space Flight Center

Tethers In Space Handbook

Edited by

M.L. Cosmo and E.C. Lorenzini

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for
NASA Marshall Space Flight Center
Grant NAG8-1160 monitored by C.C. Rupp
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Harvard-Smithsonian Center for Astrophysics

Front Cover: *(left) Photo of TSS-1 taken from the Shuttle cargo bay, 1992;*
(right) Photo of SEDS-2 in orbit taken from the ground, 1994.

1.2 The Small Expendable Deployer System (SEDS): SEDS-1 and SEDS-2 Missions

The SEDS project started as a Small Business Innovative Research contract awarded to Joe Carroll by NASA MSFC. SEDS hardware proved to be able to succesfully deploy a 20 km tether in space. Both flights of SEDS-1 (March 29, 1993) and SEDS-2 (March 9, 1994) flew as secondary payloads on Delta II launches of GPS satellites. After the third stage separation the end-mass was deployed from the second stage. SEDS-1 demonstrated the capability of deorbiting a 25 kg payload from LEO. SEDS-2, on the other end, demonstrated the use of a closed loop control law to deploy a tethered payload along the local vertical.

SEDS' hardware, as shown in figure 1.9, consists of a deployer, brake/cutter and electronics box. All the components that are in contact with the tether, except for the brake post, are coated with teflon. The deployer consists of baseplate, core, tether and canister. The tether is wound around the core. In addition there are three Light Emitting Diodes (LED). Two of the LED's are used to count the turns of deployed tether, while the third is used to check when the tether is almost completely unwound. The canister provides a protective cover for the tether and restrains it during deployment. The tether material is SPECTRA-1000.

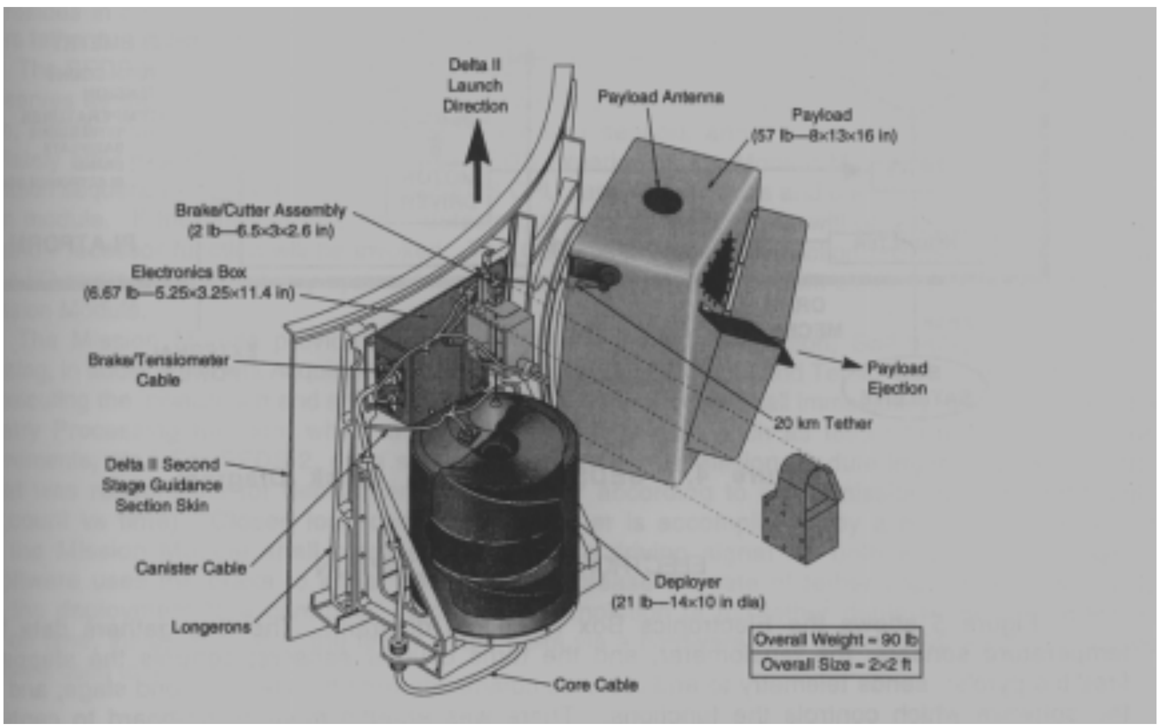

Figure 1.9 SEDS and Endmass on the Delta Second Stage

The brake/cutter components are: brake post, stepper motor, tensiometer, temperature sensor, pyro cutter, exit guide. The tether post is coated with hard anodize. The stepper motor is used to wrap or unwrap the tether to vary the deployment tension and the resulting deployment velocity. The brake mechanism is a friction multiplier and the multiplier function is proportional to the friction surface area between the tether and brake post. SEDS functional diagram is shown in figure 1.10.

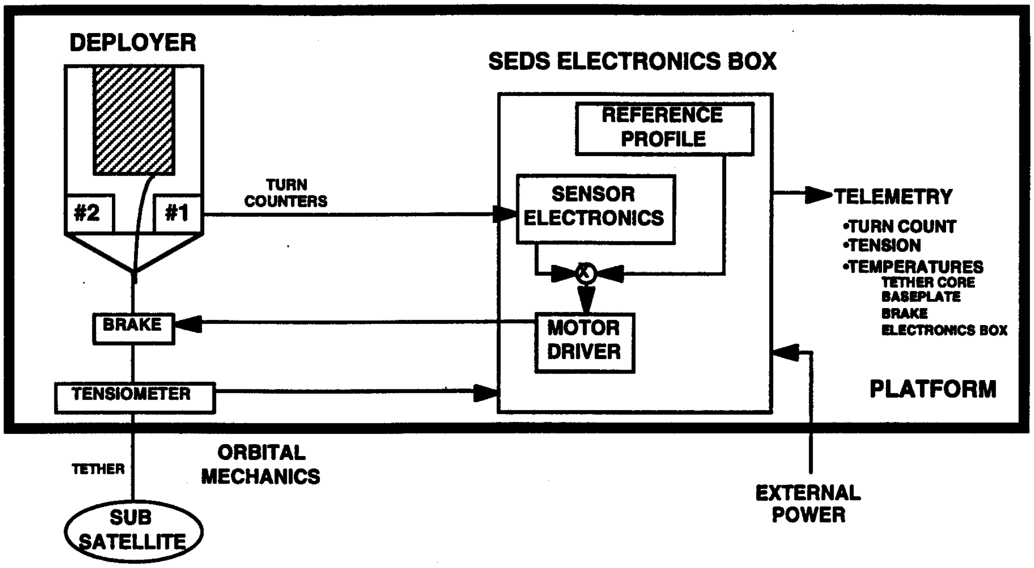

Figure 1.10 SEDS Functional Diagram

The main differences between SEDS 1 and SEDS-2 are shown in table 1. SEDS-2 closed loop was implemented by deploying the tether according to a pre-mission profile. The deployment control logic acted on the brake mechanism by increasing or decreasing the deployment velocity to follow the profile and bring the payload at the end of the tether deployment to a smooth stop along the local vertical.

Table 1. Main differences between SEDS-1 and SEDS-2

	SEDS-1	**SEDS-2**
Tether Cutter Pyrotechnics	Active	Inactive
Control Law	Open Loop	Closed Loop
Tether Solder Lumps	Study Tension Pulses	None
Tether Fabrication	Tether Application	Cortland/Hughes
Mission Initiation	Prior to Depletion Burn	After Depletion Burn
Brake Usage	Minor	Significant after 1 Km
Tether Stabilization	None	Yes

The end-mass payload (EMP) was developed by NASA LaRC in order to monitor the dynamics of a tethered susbsatellite. EMP consisted of three primary science sensors: a three-axis accelerometer, a three axis tensiometer and a three axis magnetometer. The EMP measured 40.6X30.5X20.3 cm and weighted about 26 kg. The end-mass was completely autonomous and carried its own battery, electronics, computer and S-band telemetry system. As schematic of EMP is shown in fig. 1.11. The three axis tensiometer was also developed at NASA LaRC.

SEDS-1 mission objectives were to demonstrate that SEDS hardware could be used to deploy a paylod at the end of a 20 km-long tether and study its reentry after the tether was cut. The orbit chosen had an inclination of 34 degrees and a perigee altitude of 190 km and

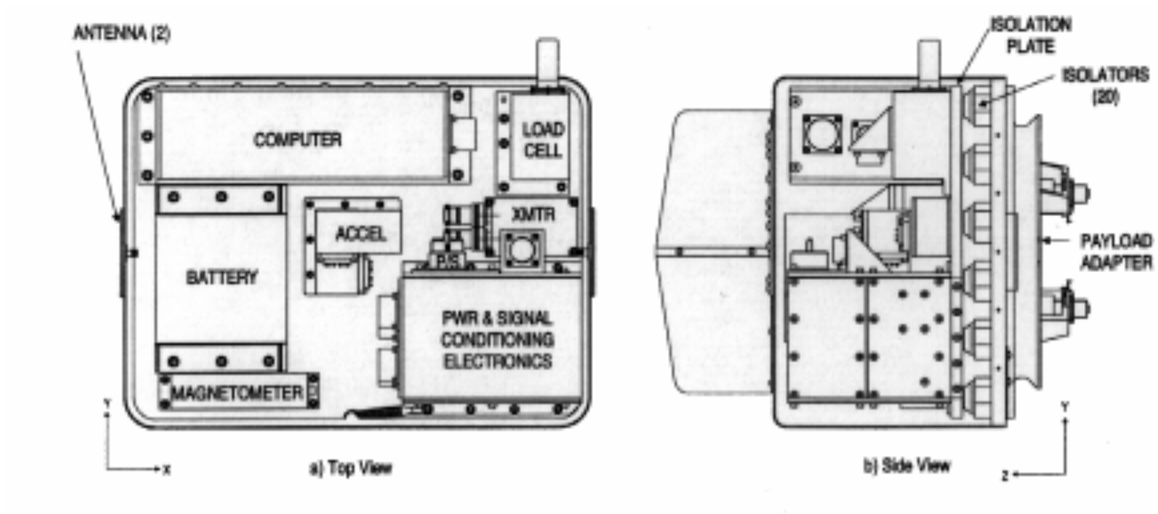

Figure 1.11 Schematic of SEDS EMP

an apogee altitude of 720 km. The EMP transmitted over 7900 seconds of data before burning into the atmosphere (1Hz sampling rate for the magnetometer and 8 Hz for the tensiometers and accelerometers). As predicted, SEDS-1 reentry was off the coast of Mexico (see fig. 1.12a). NASA stationed personnel at Cabo San Lucas, Puerto Vallarta and Manzanillo to make photographic and video observations. The Puerto Vallarta site was able to obtain observational data as shown in figure 1.12b

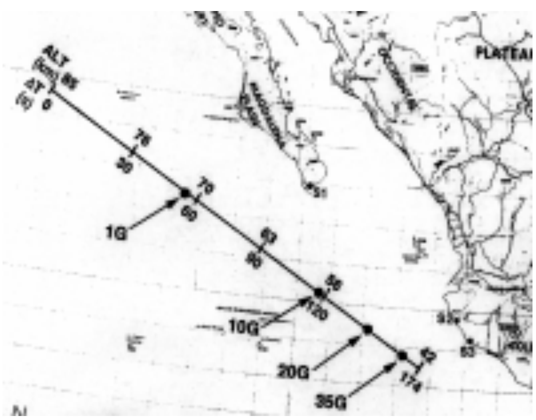

Figure 1.12a SEDS-1 EMP reentry trajectory

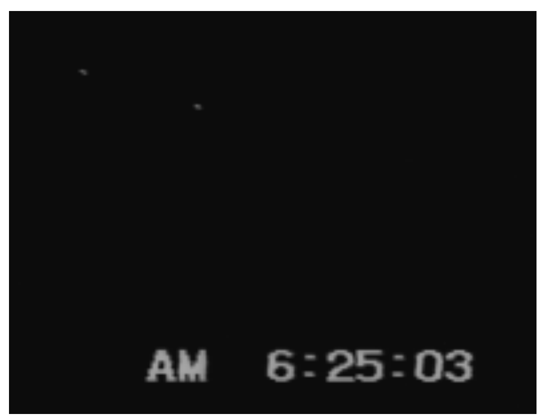

Figure 1.12b Observational Data of SEDS-1 reentry

SEDS-2 mission objectives were to demonstrate the feasibility of deploying a payload with a closed-loop control law (i.e. a predetermined trajectory) and bring it to a small final angle (<10 degrees) along the local vertical. A secondary objective was to study the long term evolution of a tethered system. The orbit this time was chosen to be circular with an altitude of about 350 km. The SEDS-2 tether was allegedly cut by a micrometeoroid or debris after five days. The EMP transmitted over 39,000 seconds of data before the battery died (1 Hz sampling rate for all the three primary science sensors).

SEDS-1 and SEDS-2 Flight Data

SEDS data base is available through anonymous ftp at the node optimu@gsfc.nasa.gov (128.183.76.209) SEDS1 data are in the subdirectory /pub/projects/tether/SEDSMission1 and SEDS-2 data are in the directory /pub/projects/tether/SEDSMission2. Each directory is organized in different subdirectories with deployer data, EMP data, radar, etc.. Each content of a directory is described in a read.me file.

SEDS-1

The turn counter data are shown in Figure 1.13a, the tension at the deployer is shown in figure 1.13b and the tether rate in 1.13c. In order to compute the tether length and its rate, the turns had to be mapped and converted into deployed length. Note that the velocity at the end of the deployment was about 7 m/s explaining the huge jump in tension and the consequent rebounds.

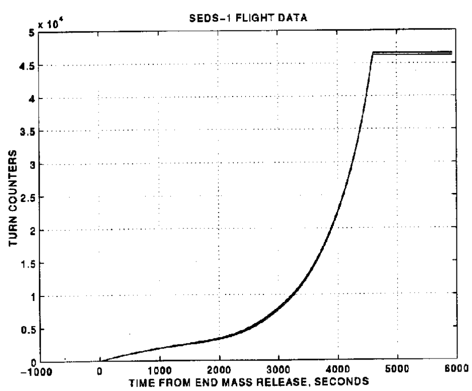

Figure 1.13a. SEDS Deployer Turns Counts

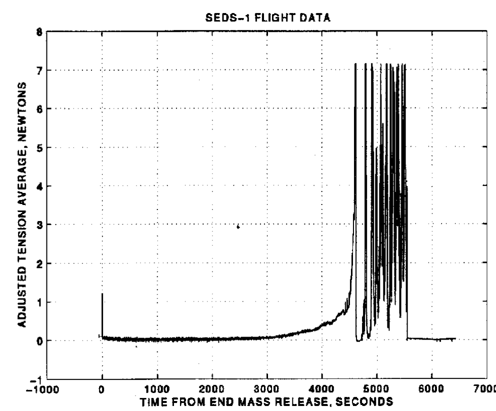

Figure 1.13b. SEDS Deployer Tension

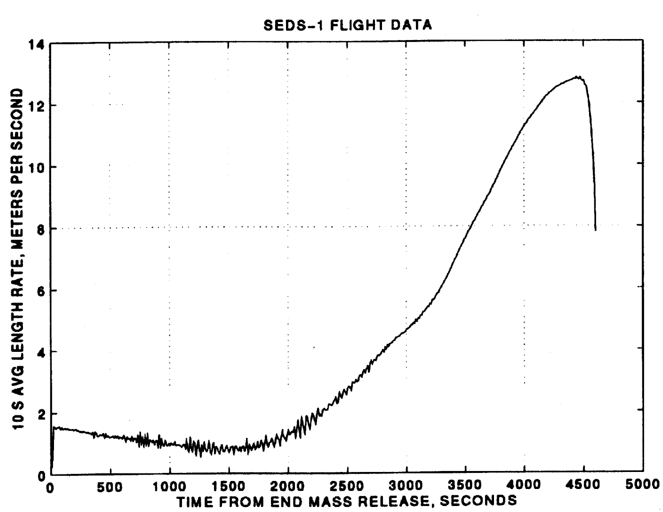

Figure 1.13c. SEDS Deployer 10-sec Average Length Rate

The magnetometer and tension moduli at the EMP are shown in figures 1.13d and 1.13e, respectively. Note that the magnetometer was affected by a bias estimated to be 3065 nT, -3355 nT and -4188 nT on the x, y and z axes, respectively. Procedures on the data calibration and validation are given at the ftp site as well as are described in several papers presented at the Washington Conference.

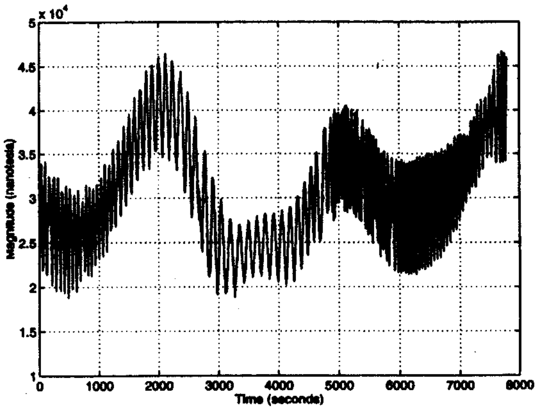

Figure 1.13d. EMP Magnetometer Modulus

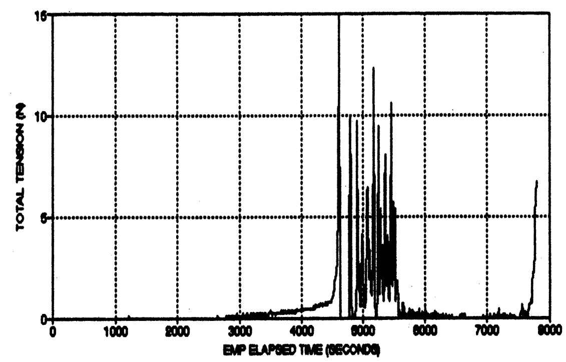

Figure 1.13e. EMP Tension Modulus

SEDS-2

The tether deployment rate and the tension at the deployer are shown in figure 1.14a, and 1.14b, respectively. The deployment law was so effective that the final tether rate was about 2 cm/s. As computed by the modulus of the EMP tension, shown in fig 1.14c, the final libration was about 4 degrees, and it was confirmed also by the radar tracking. Even in SEDS-2 the magnetometer signal was affected by a bias anomaly that was estimated to be -1128 nT, 1312 nT, and 2644 nT on the x,y and z axes, respectively.

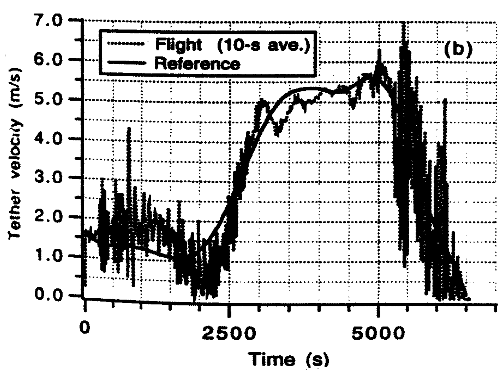

Figure 1.14a. Tether Rate

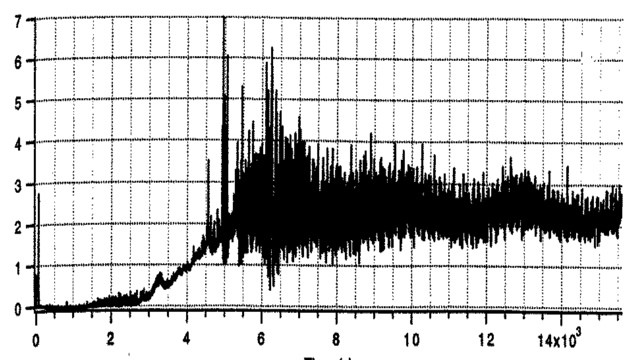

Figure 1.14b. Tension at Deployer

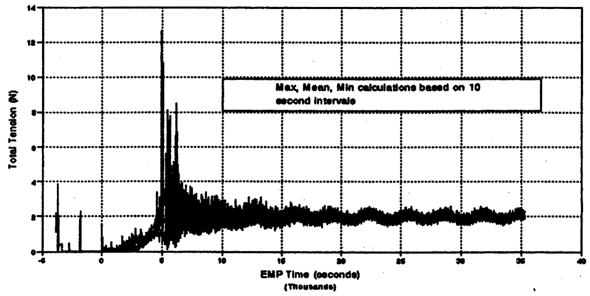

Figure 1.14c. EMP Tension Modulus

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- W.Webster - NASA/GSFC