Intricacies of Using Kevlar Cord and Thermal Knives in a Deployable Release System: Issues and Solutions

Alphonso C. Stewart[*] and Jason H. Hair[*]

Abstract

The utilization of Kevlar cord and thermal knives in a deployable release system produces a number of issues that must be addressed in the design of the system. This paper proposes design considerations that minimize the major issues, thermal knife failure, Kevlar cord relaxation, and the measurement of the cord tension. Design practices can minimize the potential for thermal knife laminate and element damage that result in failure of the knife. A process for in-situ inspection of the knife with resistance, rather than continuity, checks and 10x zoom optical imaging can detect damaged knives. Tests allow the characterization of the behavior of the particular Kevlar cord in use and the development of specific pre-stretching techniques and initial tension values needed to meet requirements. A new method can accurately measure the tension of the Kevlar cord using a guitar tuner, because more conventional methods do not apply to arimid cords such as Kevlar.

Introduction

The Microwave Anisotropy Probe (MAP) Spacecraft utilized a novel Solar Array Restraint and Release System (SARRS) design that featured a Kevlar cord and thermal knives as the primary solar panel restraint and release components. The 7.6 m (300 in) Kevlar cord encircled the spacecraft to secure the solar panels in their stowed configuration for launch. Once in orbit, one of two redundantly configured thermal knives severed the Kevlar cord and permitted the panels to deploy.

A number of issues arose during the SARRS development involving the thermal knives, Kevlar cord behavior, and the measurement of the tension in the Kevlar cord. The issues encountered and their solutions will be discussed, including a process for examining the thermal knives after each use, a procedure for characterizing the Kevlar cord behavior in different environments, and a method for measuring the tension in the cord using a guitar tuner. The solutions are presented in a general manner such that the information can be applied to other configurations of Kevlar cord and thermal knives. The discussion is preceded by a brief introduction of the MAP Spacecraft and the SARRS Configuration.

SARRS and MAP Spacecraft Configuration

The purpose of the MAP mission is to perform a full sky scan of the cosmic microwave background in order to study the origin of the Universe. MAP was designed, fabricated, and tested at NASA's Goddard Space Flight Center as part of the Medium Class Explorers (MIDEX) program. MAP was launched in to low earth orbit by a Delta II 7425-10 launch vehicle from the Eastern Range on June 30, 2001. After separation from the launch vehicle, the solar arrays and sun shield were deployed and the spacecraft continued on to orbit about the L2 Lagrange point.

Spacecraft Configuration

The MAP spacecraft uses a passively cooled microwave differencing assembly to measure the full sky cosmic background at a temperature of 2.7 K. Since the microwave instrument must be kept very cold, the solar arrays have been configured to form part of the sunshield that will always shade the instrument from the sun. The microwave instrument is mounted on top of a hexagonal spacecraft bus and the protective solar array and sun shield combination is mounted to the bottom of the bus, as shown in Figure 1 below.

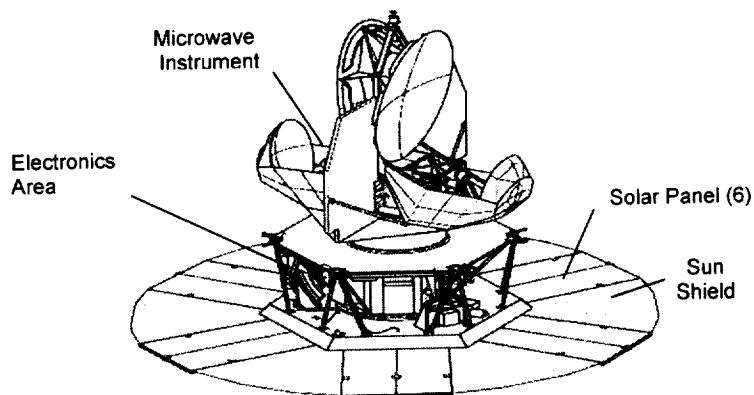[*] NASA – Goddard Space Flight Center, Code 543, Greenbelt, MD

Figure 1. MAP Spacecraft Deployed Configuration

The sun shield deploys to a diameter of 5.1 m (200 in) from a diameter of 2.7 m (108 in) in the stowed configuration, which is shown in Figure 2 below. The entire spacecraft has a mass of 840 kg (1,850 lb).

Restrain System Requirements
The primary objective of the SARRS was to secure the solar panels and sun shield in the stowed configuration for launch and ground transportation, but all of the main design requirements were met:

1. Consume less than 20 watts of power in less than 150 seconds per activation;
2. Allow the spacecraft to remain inside the launch fairing for up to 45 days without servicing;
3. Release the solar panels for deployment within 150 seconds;
4. Design mass less than 4 kg; and,
5. Complete SARRS development within schedule.

SARRS Configuration: Kevlar Cord and Thermal Knife
The MAP SARRS was designed to meet all the requirements and address other issues such as actuator cost, delivery schedule, ability to test the flight components, access to restraint components during stowage, and risk of potential solar cell damage during deployment. The restraint portion of the SARRS consists of one 3 mm (0.12 in) diameter Kevlar cord[1] assembly that encircles the six solar panels by resting on twelve cord standoffs. The release portion is composed of two, one primary and one redundant, thermal knives[2]. The complete SARRS configuration is shown in Figure 2 below.

---

[1] Type 72, Ashaway Line and Twine Manufacturing, Co.
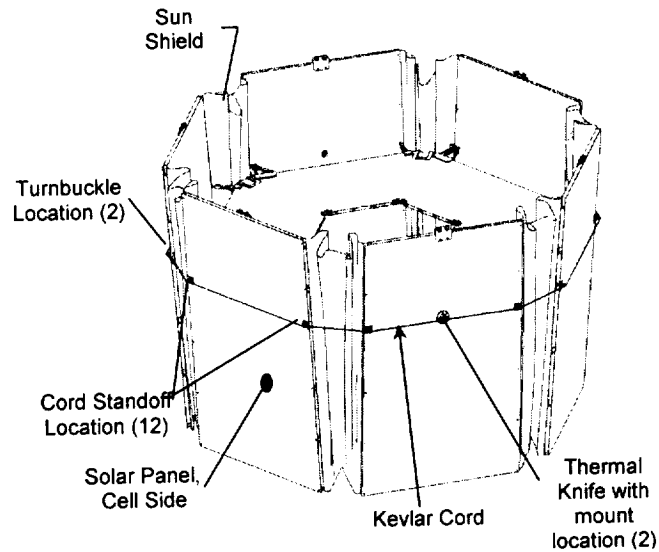[2] Model R09686-407, Fokker Space, Sa.

Figure 2. SARRS Configuration (Instrument not shown)

Two cord standoffs, shown in detail in Figure 3 below, are positioned on the outer edges of each solar panel. The standoffs position the cord 33 mm (1.3 in) above the solar cells in order to provide enough clearance in front of the solar cells such that the cord will not contact and damage the cells during release.
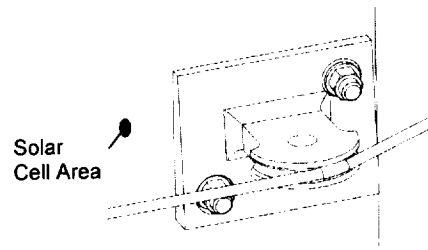

Figure 3. Cord Standoff with Kevlar Cord

There are two thermal knives in the SARRS. Each knife is held in a mount, shown in Figure 4 below, which is attached to one of two solar panels on opposite sides of the spacecraft. The cord standoffs and mounts are positioned such that the cord remains in contact with the thermal knife heater element, which is pressed towards the Kevlar cord by a spring within the thermal knife component.
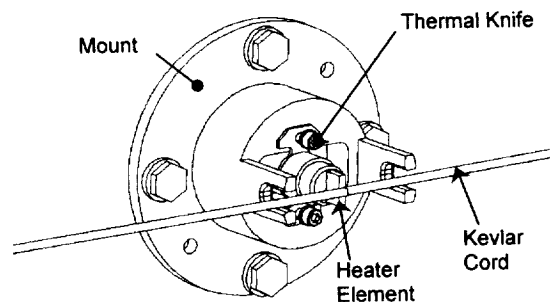

Figure 4. Thermal Knife in Mount

To deploy the solar panels, power is applied to either of the two thermal knives, which generate temperatures in excess of 1000 °C at the tip of their respective heating elements. The thermal knife then begins to sever the Kevlar cord by melting through the fibers, degrading the tensile strength of the Kevlar cord. The degradation continues until cord's strain energy suddenly breaks the remaining fibers, allowing the cord to fly free of the spacecraft, releasing the panels.

Kevlar Cord Configuration
The cord assembly is constructed of two Kevlar cord sections, each 3.8 m (150 in) in length, that are joined by two turnbuckles made from titanium, as shown in Figure 5 below. The turnbuckles are used to increase the cord tension during installation, as the Kevlar cord requires a large strain, about 300 mm (12 in) to achieve the proper tension. The Kevlar cord is constructed of woven Kevlar fibers that are at various angles with respect to the tension load. When tension is applied, the fibers try to align themselves along the load direction and extend the cord length. However, it was found that pre-stretching the Kevlar cord would increase the cord stiffness, thus requiring a shorter turnbuckle to achieve the same load. After assembly, the cord was pre-stretched by cycling the cord with a 157 N (700 lb) load 10 times for 3 min each time. This process is discussed in more detail in the Kevlar Cord Behavior section below.

The turnbuckles are located between the solar panels in two locations 180 degrees apart and 90 degrees away from the thermal knives, as shown in Figure 2 above. The advantages of this configuration are a more distributed cord load during tensioning and the mitigation of potential solar cell damage during cord release.
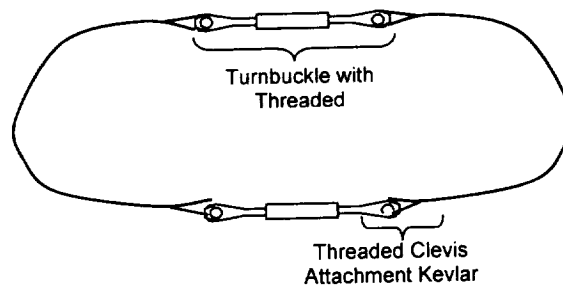
Turnbuckle with
Threaded

Threaded Clevis
Attachment Kevlar

Figure 5. Kevlar Cord with Turnbuckles

In addition to generating large strain, the Kevlar cord weave pattern generates a compressive force towards the cord center when tension load is applied. This behavior enables the Kevlar cord to be attached to the turnbuckle with a simple but effective loop that relies entirely on internal frictional forces from the braided pattern, as shown in Figure 6 below. This design allows a cord assembly to develop its maximum breaking strength characteristics by avoiding strength reducing knots.
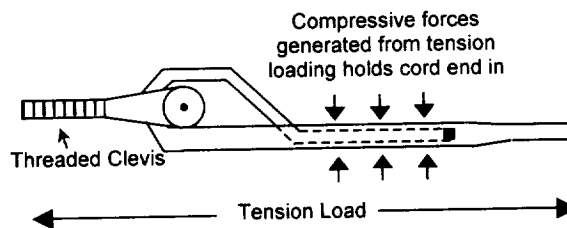
Compressive forces
generated from tension
loading holds cord end in

Threaded Clevis

Tension Load

Figure 6. Kevlar to Turnbuckle Attachment

Kevlar Cord Release Mechanism: Thermal Knife

The thermal knife was originally developed by Fokker Space and has successfully been used on numerous flight programs. The thermal knife component was selected as part of the SARRS during the initial design phase. It was also decided that there would be no modifications made to the thermal knife because of its successful flight heritage. However, the differences in the knife's utilization in the SARRS would require an extensive development and test program.

Thermal Knife Description

The thermal knife (T/K) consists of a ceramic substrate heater element, 8x10x 0.7 mm (0.3x0.4x0.03 in), with dual electrical resistance trace patterns. The trace patterns heat the substrate to temperatures in excess of 1000 °C. Two pins support the heater element and provide the electrical power to the parallel trace patterns. The pins and heater element are held in a cylindrical housing and a spring inside the housing preloads the heater element to push it against the Kevlar cord during the cutting process.
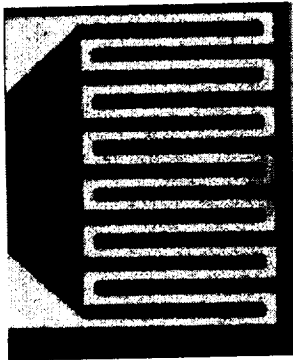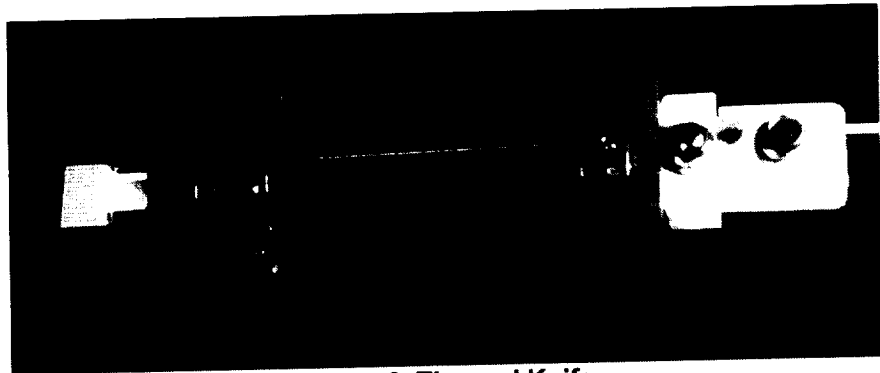

Figure 7. T/K Heater Element with Trace

Figure 8. Thermal Knife

T/K Use

The MAP SARRS uses a redundant thermal knife configuration that is different than previous thermal knife release system designs. This design allows either knife to operate and release the system. In addition, the operation of one knife will not damage the redundant knife and a failure (electrical or mechanical) will not interfere with operation of the other knife.

Trace Damage

The thermal knife trace material becomes soft when the substrate is heated and is more susceptible to damage during this period. It is important to maintain minimum contact between the Kevlar cord and trace during the cutting process. For the MAP SARRS, minimum contact is achieved by using a minimum diameter Kevlar cord, large strain v alue, a nd a continuous 90-degree angular contact configuration between the cord and heater element.

The SARRS Kevlar cord is less than 3 mm (0.12 in) in diameter. This relatively small diameter combined with large strain allows the Kevlar fibers to pull away from the trace during the cutting process, as shown in Figure 9 below. On the contrary, a smaller strain value and larger cord diameter causes the severed fiber ends to adhere to the trace during activation and in some instances pull the trace off the substrate when the Kevlar cord is completely severed and separates, as shown in Figure 10 below. In this instance, the Kevlar cutting process would not be affected during the initial trace damage, however, all subsequent cuts would be affected by an already damaged trace.
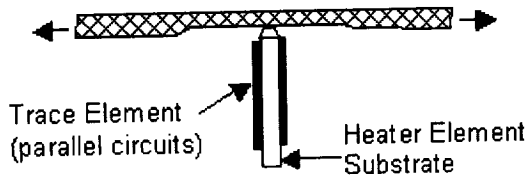
Figure 9. T/K Element and Small Diameter Kevlar with Large Strain Kevlar (MAP design)
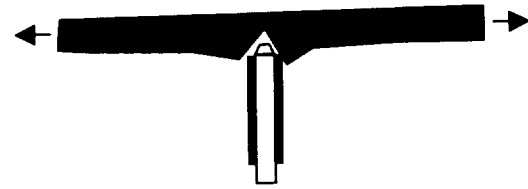

Figure 10. T/K Element and Large Diameter Kevlar with Low Strain

In the MAP SARRS design, the Kevlar cord maintains a near 90-degree angle with the heater element surface, as shown in Figure 11 below. As the trace element is located close to substrate edge, a less than 90-degree angle brings the cord closer to the heater element trace, as in Figure 12 below. With this configuration, there is an increased risk of damaging the trace as the Kevlar cord travels around the heater element edge. The damage to the trace occurs once the fibers have been severed, thus the damage would not become apparent until the subsequent activation.
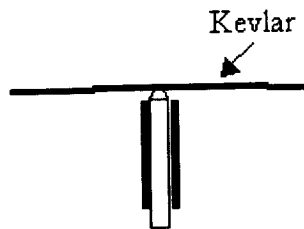

Figure 11. MAP SARRS T/K and Kevlar Cord Configuration
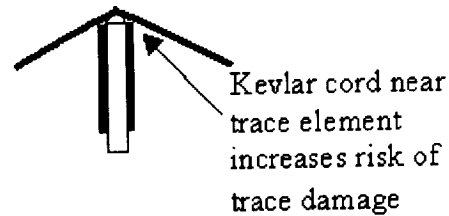

Figure 12. T/K with Kevlar Cord Less than 90-degree Angle

When inspecting the knife after a cut, a continuity check may not reveal the presences of trace damage in all cases. A resistance measurement must be made to insure the electrical integrity. In addition, for the MAP SARRS, a visual inspection (20X magnification) was performed prior to and after final ground activation to insure trace integrity. The inspection was possible because the SARRS design allows the thermal knife heater element to be exposed after it severs the cord. A long-range microscope was used to inspect and record the trace condition.

The MAP SARRS never experienced the potential thermal knife problems cited above or any other problems, due to its thermal knife configuration. However, there have been some issues with the thermal knife on other projects. After those projects investigated their problems, solutions were suggested, but the SARRS was already in compliance with those suggestions. Thus, the MAP SARRS configuration has been supported by much more information than can be presented under the scope of MAP, and those data will most likely be presented in the future.

Kevlar Cord Behavior

The SARRS cord tension requirement was bound by minimum and maximum values of 45 N (200 lb) and 110N (490 lb), respectively. The minimum tension was the tension required to secure the solar panels against their stops such that gapping did not occur during launch. The maximum value was based on the spacecraft structure's ability to withstand the compression induced by the cord tension. In addition, the tension must be maintained above the minimum for 45 days on the launch pad and during the launch environment. A series of tests were performed to determine the Kevlar cord tension characteristics under these conditions.

Time, pre-conditioning, humidity, and temperature all affect the SARRS Kevlar tension load and relaxation rate. A series of tests were performed to investigate the individual and combined effects that each of these conditions would have on the Kevlar cord tension.

The cord assembly has a total unloaded length of 7.62 m (300 in). It was not feasible to place this entire length within the available test chamber. Therefore, a test was performed to investigate the feasibility of testing shorter cord lengths and applying the results to longer lengths. These results proved to be positive, so it was decided to proceed with testing using cord samples that were shorter than the flight cords.

Relaxation From Final Stowage To On-orbit Deployment
Early testing showed that the Kevlar cord, as delivered, would lose tension very rapidly with respect to time. In an effort to reduce the tension loss over time, a pre-conditioning, or pre-stretching, process was developed and improved during the development of the SARRS. The final process involved pre-stretching the cord by tensioning it with 157 N (700 lb) 10 times for 3 min each time. Then it was installed on the spacecraft and tensioned to the initial tension. After at least 24 hours, the cord was re-tensioned to its initial tension. Variations of this process are evident throughout the characterization process as this final process was derived.

Several tests were performed that subjected tensioned Kevlar cord samples to a simulated environment from cord installation to on-orbit deployment. The initial purpose of these tests was to determine the relaxation rate and final cord tension at the end of a 45-day period. Later, the test was extended to include the launch environment. The goal was to demonstrate that a pre-stretched Kevlar cord could maintain a minimum tension of 45 N (200 lb) throughout the required time interval.

A Kevlar test specimen of 41 cm (16 in) was used in the first test. A typical test fixture with Kevlar cord specimen and load cell is shown in Figure 13 below. The specimen was pre-stretched by cycling the tension to 112 N (500 lb) ten times at three minutes duration and immediately placed in the test fixture at 62 N (275 lb). Two days after the initial loading, a relaxation plot, Figure 14, projected that the cord would not maintain the minimum tension for the required 45-day period. The specimen was reloaded to its initial value and a new 45-day period was started.
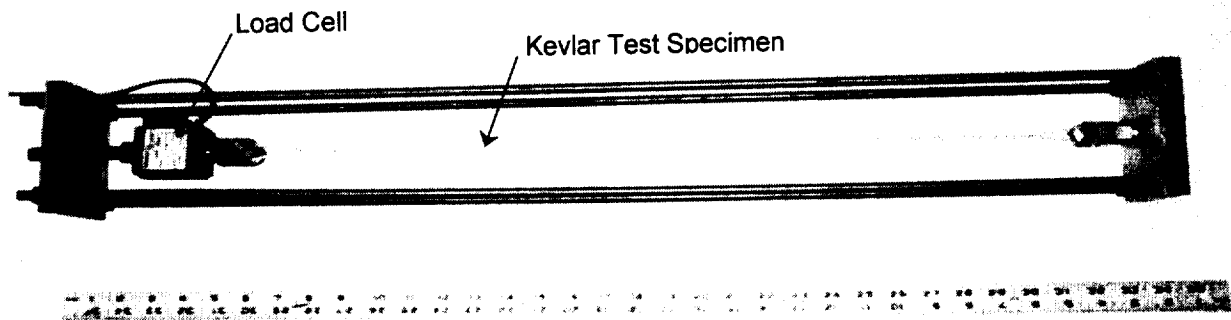

Figure 13. Load Relaxation Test Fixture

During the first 10 days of the new cycle it became apparent that the ambient humidity fluctuations were affecting the load relaxation rate. To determine the magnitude of the humidity effects, the specimen was placed in a humidity-controlled ("Glove") box so the tension load could be monitored as a function of relative humidity. Each time the humidity setting was changed, the cord load readings would change according to approximately 0.5 N (2.5 lb) per % change in relative humidity (RH). At day 24 the RH was set to 40% for the remaining duration of the test. The rate of relaxation during this period was constant.
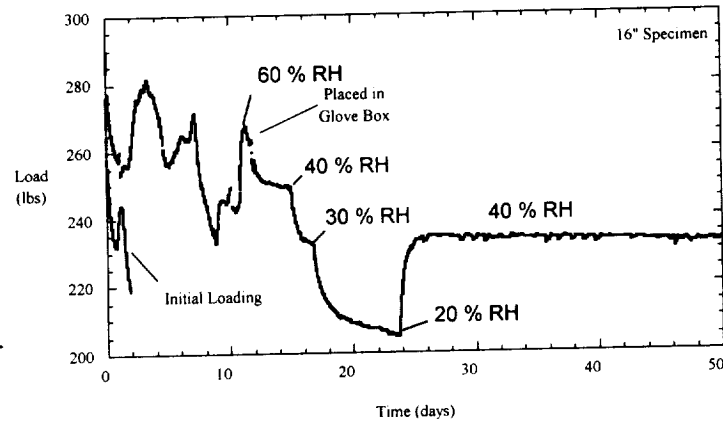
Figure 14. Load Over Time with Varying Relative Humidity

Load Change in Vacuum

An additional test to simulate the launch environment was conducted with two 64 cm (25 in) Kevlar specimens. The specimens were exposed to full vacuum within 10 minutes (37% RH to 0 % RH) after being pre-stretched (10 times/ 3 min duration with 112 N) and then loaded to 70 N (310 lb). The total load loss for both specimens was 17 N (75 lb) after 24 hours, or approximately 0.5 N (2 lb) per percent humidity. Figure 15 below illustrates the rate of tension loss while the cord was under vacuum.
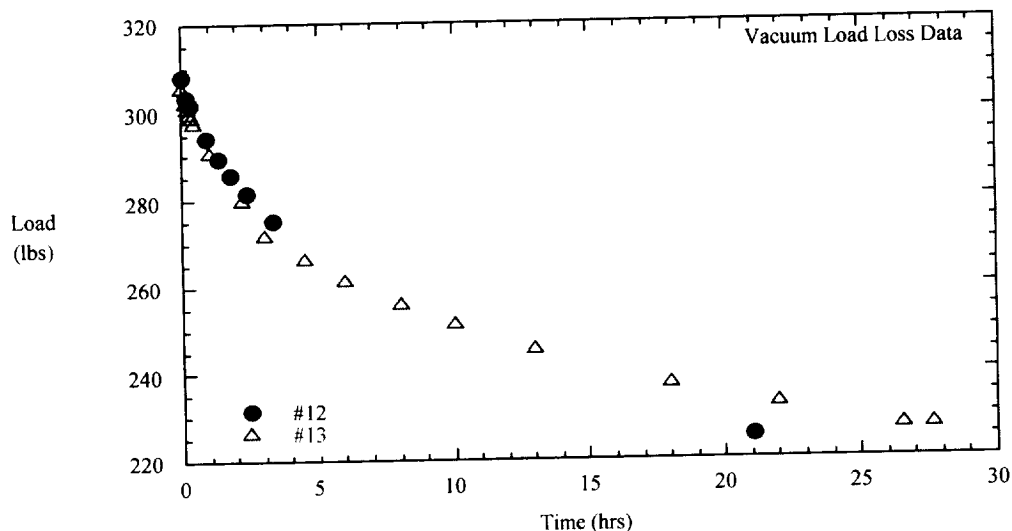

Figure 15. Kevlar Tension Loss under Vacuum

Relaxation Rate Versus Time with Constant Relative Humidity

A test was designed to determine the SARRS cord relaxation rate and whether the initial tension load would affect the rate. Four Kevlar cord specimens 64 cm (25 in) were preloaded 10 times each to 157 N (700 lb) for 3 minutes duration. The cords were tensioned to 74, 80, 85, and 91 N in a humidity environment of ~ 40% RH. It was noted that prior to placing the specimens in the test chamber the tension was decreasing rapidly. The tensions were reloaded to their initial values three times within a 50-minute period. Each time the specimens were reloaded the relaxation rate decreased. After the third reloading, the specimens were placed in an enclosed environment that maintained 22-24 °C at 50% RH.

The tension values were continuously monitored for 45 days and the results are shown in Figure 16 below.

The loads were plotted verses time on a logarithmic scale. The load increase at day 9 resulted from an error in the test chamber humidity setting. From the plot, the rate of relaxation was independent of the initial tension and decreased an average of 5% per order of magnitude. Based on the slope, the cord lost 5% of the initial tension within the first day, another 5% by day 10, and another projected 5% by day 100 after the final reloading. Thus, the cord would lose less than 15% of if its initial tension after 45 days.

Humidity set to 50% RH
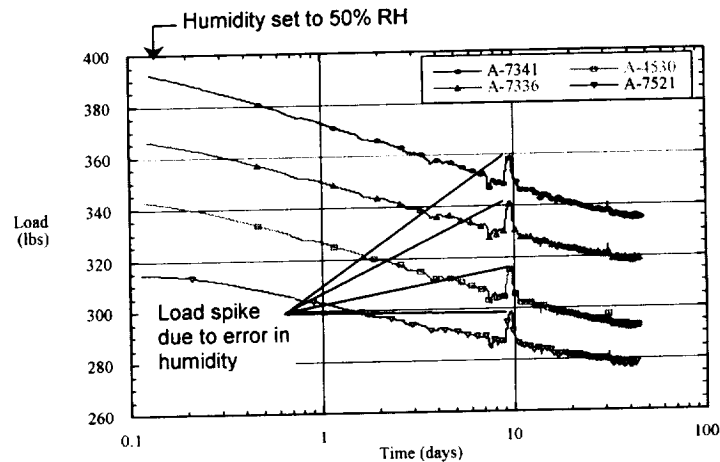
Load spike
due to error in
humidity

Figure 16. 45-Day Cord Relaxation Rate

Temperature Effects

A test was performed to determine the temperature effects on the SARRS cord. A typical load versus temperature plot was generated from temperature and load profile data, as in Figure 17 below. Below 40 °C the Kevlar tension changed at a rate of 0.2 N (0.9 lb) per degree Celsius and the rate of change above 40 °C was less, so it was assumed to be zero.

Figure 17. Load vs. Temperature

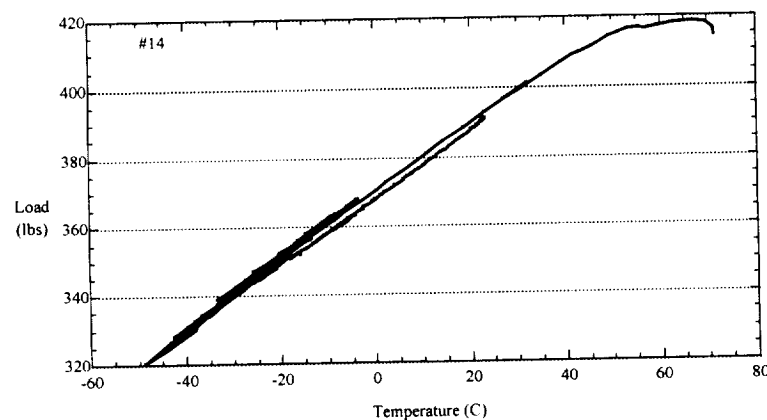## Cord Tension Prediction

There was no access to monitor the cord tension after fairing installation and during the potential 45 days on the launch pad. However, it was possible to estimate the SARRS cord tension at any point from the last measurement to deployment. The calculations were based on the above test results of relaxation rates due to time, relative humidity changes, and temperature.

Table 1. Calculating the Resultant Cord Tension Given the Environment

As an example, given:		The minimum tension during launch would be:	
Installation Tension	76.4 N (340 lb)	Installation Tension	76.4 N (340 lb)
Humidity during installation	46% RH	Change in % RH (6 x 0.5N)	- 3.3 N (15 lb)
Time on launch Pad	10 days	Time on Pad (0.1 x 76.4N)	- 7.6 N (34 lb)
Humidity during 10 day period	40% RH	Vacuum (3.3N / hr)	- 5.2 N (23 lb)
Pad Temperature	18 °C	Delta Temperature (17 °C)	+ 3.3 N (15 lb)
Orbit Temperature	35 °C		
Deployment in 1.5 hours		Minimum Launch Tension	63.6 N (283 lb)

Kevlar Cord Tension Measurement

As described in the Background Section above, the MAP SARRS relies on a Kevlar cord to restrain the six solar panels in their stowed configuration during launch. The cord must maintain a minimum tension to eliminate vibration impact between the solar panels and the spacecraft bus during launch and to fly away from the probe when released. In addition, the minimum tension must be maintained for at least 45 days in case of launch delays. During SARRS development, it was found that the Kevlar cord has a creep characteristic that causes it to relax and loose tension over time as discussed in the section above. In order to help characterize the creep characteristic and to ensure that the proper initial tension is applied to the cord before launch, accurate and reliable tension measurements had to be made.

Issues
It was soon discovered that the original method employed to measure the cord tension, the use of a three-point tensiometer, the only commonly used method of measuring cable tension, proved to not work for Kevlar cord.

Three-point tensiometers are used in the standard method to measure the tension in stainless steel cables. These hand-held devices measure a cable's tension by bending it around two posts and a plunger as shown in Figure 18 below. The device measures the force on the plunger from the bent cable and a chart calibrated specifically for the type and weave of the cable translates this force into the tension in the cable. This method works well for stainless steel cables.
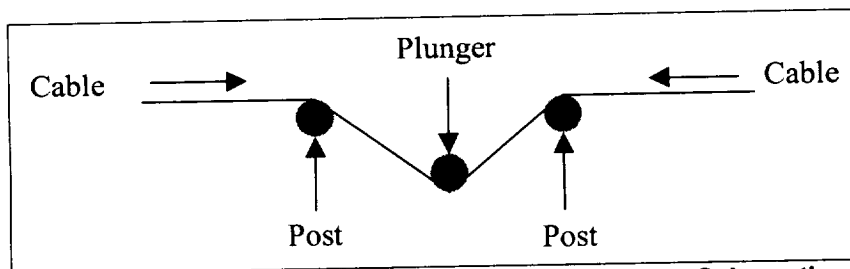
Figure 18. Three Point Tensiometer Schematic

However, it was found that a Tensitron three-point tensiometer did not work well with the Kevlar cord. Its measurements varied by 17% along one continuous, section of cord, supported only at the ends, where the tension is actually the same along the entire section. Also, repeated tension measurements made by the tensiometer in the same location on the cord varied by up to 10%.

Observation of the cord after a tension measurement by the tensiometer revealed that the tensiometer was permanently deforming the cord and leaving a crimp, resulting in measurement errors. Also, the tensiometer attempted to increase the length of the cord during measurement by stretching it, but the friction at the cord standoffs did not allow for the stretching force to be absorbed by the entire length of the cord, and, thus, greatly increased the tension in the local section being measured. The crimp and the friction phenomena led to the belief that the problem was with the method of the three-point tensionmeter, rather than the particular device itself.

Based on these issues, it is not possible for the three-point tensiomenter to measure the Kevlar cord tension sufficiently to meet MAP's requirements and must be replaced. Another existing measurement method could not be found for Kevlar, so a new method was developed to meet the system requirements.

Solution
The development of a new tension measurement system began with the following design requirements:

- Measure the tension in the Kevlar cord to within plus or minus 4 percent within the desired 22 to 101 N (100 to 450 lb) range
- Repeatedly measure the tension in the cord within the same section within the given tolerance range
- Be capable of single hand use that can safely be used to measure the cord within close proximity to the flight solar panels with minimal risk to the flight hardware

After considering a few other options, a rather simple solution was found, the Musical Pitch Method (MPM). The MPM uses an innovative process to accurately measure tension in cords made from Kevlar by combing music theory and physics relations.

The MPM employs an off-the-shelf chromatic tuner with a clip-on pick-up, a type of microphone, shown in Figure 19 below, to determine the tension in Kevlar cord. Musicians use these tuners to tune musical instruments. The chromatic tuner measures the musical note, or pitch, that emanates from a free section of cord with fixed end conditions when plucked like a guitar string. The tuner's microphone can measure the pitch, but the clip-on pick-up eliminates the effect of background noise. Music theory assigns a frequency to each musical pitch, so, by measuring the pitch, the tuner measures the frequency of the vibrating cord. A physics formula translates the frequency to the tension based the section's node length and the cord's mass per unit length.
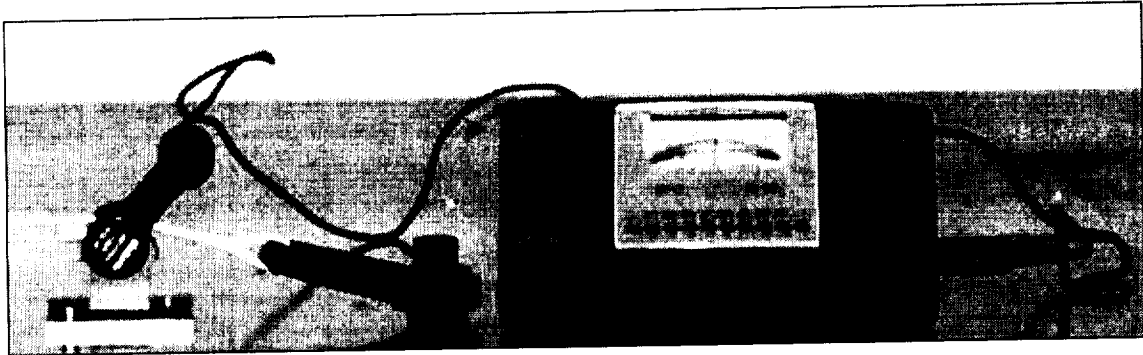

Figure 19. The chromatic tuner with the clip-on pick-up

Frequency Measurement
The chromatic tuner measures musical pitches by providing information about the octave, note, and cent deviation from a perfect musical note. The musical note information must then be translated into frequency measurements via music theory definitions.

Each musical note has an assigned frequency. By definition, the A above middle C represents a frequency of 440 Hertz (Hz). Twelve notes form an octave, C, C#, D, D#, E, F, F#, G, G#, A, A#, B, with the # representing a sharp, so C# is C sharp. Similarly named notes in different octaves represent frequencies that differ by a multiple of two. For example, the A in the octave below middle C represents a frequency of 220 Hz. This sequence repeats itself in the next octave. The steps between each of the twelve notes are known as half steps. Notice that B# or E# do not exist. That is because there is a natural half step between E, F and B, C. The frequency of each note between the A in one octave and the A in the next octave are determined by the proper fraction of a multiple of two. For example, the frequency of the A# above the A with a frequency of 440 Hz is determined by $440*(2^{(1/12)}) = 466.1$. Table 2 below

shows the frequency that each note represents for the three octaves within MAP's Kevlar cord tension range.

Table 2. Frequencies that each musical note represents in octaves -1,0, and 1

Low Octave (-1)			Middle Octave (0)			High Octave (+1)	
Note	Frequency (Hz)		Note	Frequency (Hz)		Note	Frequency (Hz)
C	130.8		C	261.6		C	523.2
C#	138.6		C#	277.2		C#	554.3
D	146.8		D	293.6		D	587.3
D#	155.5		D#	311.1		D#	622.2
E	164.8		E	329.6		E	659.2
F	174.6		F	349.2		F	698.4
F#	185.0		F#	370.0		F#	739.9
G	196.0		G	392.0		G	783.9
G#	207.6		G#	415.3		G#	830.5
A	220.0		A	440.0		A	879.9
A#	233.1		A#	466.1		A#	932.2
B	246.9		B	493.8		B	987.7

A measured pitch can deviate from a perfect musical tone. The chromatic tuner gives readings in terms of cent deviations that range from –50 to +50. The cent scale corresponds to percent, but differs numerically, as the cent reading equals the percent distance between two notes. The cent size does not relate to the percent deviation from the frequency of the note measured. The cent size differs depending on which notes the measurement spans. If the tuner reads C+50 cent, the pitch lies halfway between a C and a C# and, in turn, the frequency lies halfway between the frequencies for a C and a C#. If the tuner reads C+30 cent, then the measured tone is 30% of the distance between C and C# from C, and the frequency equals that of C plus 30% times the difference in the frequencies of C# and C. The pitch and frequencies for C+50 cent and C# -50 cent are equal. Table 3 below shows the frequencies for the cent values between middle C and C#.

Table 3. Frequencies for the cent values between middle C and C#

Note (cent)	Frequency (Hz)
C	261.6
C - (+10)	263.2
C - (+20)	264.7
C - (+30)	266.3
C - (+40)	267.8
C - (+50)	269.4
C# - (-50)	269.4
C# - (-40)	270.9
C# - (-30)	272.5
C# - (-20)	274.0
C# - (-10)	275.6
C#	277.2

Tension Conversion

Now that the frequency of the section of cord is known, Equation 1 below, which is derived from the wave equation, can be used to determine the cord tension. In Equation 1, the Tension T is dependent on the frequency γ, the node length L, and the mass per unit length μ of the section of cord.

$$(2\gamma L)^2 \mu = T \tag{1}$$

Equation 1 represents the general case and does not take stiffness or friction into account. It is possible to solve the wave equation for the tension in the string while taking into account these factors, but the solution is cumbersome and correction factors are still needed because of many variables in the construction of the cord (i.e. weave, pre-stretch).

In order to calibrate the MPM for the particular properties of the cord used for MAP, tests were performed by tensioning a sample section of cord to known values and measuring the tension with the MPM. Charts could then be made that calibrated the chromatic tuner readings with the proper tension in the cord, as the tests proved that the effects of cord construction on the first harmonic frequency became constant. The correction factors incorporated into the physics equation allowed the MPM to give accurate and precise measurements of the cord tension.

The Musical Pitch Method demonstrated that it could measure the tension in the MAP Kevlar cord accurately, as the conversion tables that used to translate the musical pitch to cord tension were calibrated to within plus or minus 2%. This measurement technique does not permanently deform the cord, thus making it more accurate than the three-point tensiometer. The Musical Pitch Method met the project requirements based on its accuracy and ease of use and was used to tension the Kevlar cord on MAP before launch.

Conclusions

The MAP SARRS operated successfully after the launch of the spacecraft. The thermal knife severed the Kevlar cord as demonstrated in the thermal vacuum deployment tests. The SARRS design and extensive test program were the main reasons for its success. The method for measuring the Kevlar cord tension is a new approach and was developed at GSFC. This method is applicable to all arimid cord configurations that are tensioned to level at which an audible sound is made when it is excited (plucked). The thermal knife can be used successfully as a release system as demonstrated in various missions including MAP. In utilizing the knife and Kevlar cord combination one should be aware of the potential problems.

The SARRS design offers solutions to some of the potential thermal knife problems. First, keep the cord diameter to a minimum and provide enough stain to pull the severed fibers away from heater element during activation. This configuration will minimize the chances of the severed fibers adhering to the trace prior to final separation and causing damage. Finally, inspect the heater element before and after actuation. Damage to the trace usually occurs during cord separation, and subsequent activation will be affected by the existing damage. A Continuity check alone may not reveal a damaged trace. The list of issues and recommendations cited in this report were based on the features in the SARRS design that addresses them. GSFC is currently compiling the investigation results of the thermal knife issues and solutions from other programs. This report will be presented in the near future.

References

Marion, Jerry B., and Hornyak, William F., "Part 1: Physics for Science and Engineering," CBS College Publishing (1982) pp. 512-519.