# Jettison System for a Large Inflatable Antenna

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## Abstract

This paper describes a jettison system used to separate a large, inflatable-deployable antenna from a free-flying spacecraft. The jettison system consists of four discrete Marman band clamps, released simultaneously via pyrotechnics. The design, analysis, analytical simulation, and testing of the system are discussed. Of particular note is the correlation of test results with the Marman band design calculations.

## Introduction & Mission Overview

The Spartan Inflatable Antenna Experiment (IAE) is a Space Shuttle-borne experiment designed to test the function and performance of an inflatable-deployable antenna reflector and structure in space. Described in this paper, the jettison system is key to the mission performance, since it separates the inflated antenna structure from the Spartan carrier spacecraft, thereby allowing the Spartan carrier to be retrieved by the Shuttle. The Spartan carrier and the IAE are briefly described to provide an understanding of the jettison system design requirements and constraints.

The Spartan Program provides access to low Earth orbit via the Space Shuttle and the Spartan carrier system. Spartan is an autonomous, reusable, 3-axis stabilized free flying spacecraft[1]. It is carried into orbit, deployed, and retrieved by the Shuttle. Spartan's simple, relatively generic interfaces to the Shuttle streamline and simplify both payload certification and accommodation on Shuttle missions. For each mission, the basic spacecraft system is adapted to accommodate the experiments while retaining the generic Spartan attitude control, command and data systems, thermal, and structural systems. The Spartan IAE spacecraft is shown in Figure 1.

The Inflatable Antenna Experiment [2] consists of an inflatable antenna approximately 31 m (101.7 ft) in length with a 14-meter (45.9-ft) off-axis parabolic reflector, cameras to record the antenna inflation, and optical equipment to measure the reflector surface precision. The reflector is aluminized Mylar with a clear Mylar canopy and is inflated to 0.00207 kPa (0.0003 psi). The inflatable structure consists of three struts and a torus made of neoprene-coated Kevlar and is inflated to 20.7 kPa (3 psi). The experiment objective is to demonstrate an antenna surface accuracy of 1 mm RMS. Figure 2 shows the inflated antenna, attached to the Spartan carrier. The antenna is deployed and inflated after the Shuttle crew has both released the Spartan spacecraft into autonomous free flight and maneuvered to a safe separation distance. The experiment will be completed in approximately 90 minutes after which the inflated antenna will be jettisoned from the Spartan carrier. The Spartan carrier is retrieved and re-berthed in the Shuttle bay. The overall mission scenario is shown in Figure 3.

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**Spartan IAE spacecraft with stowed antenna**
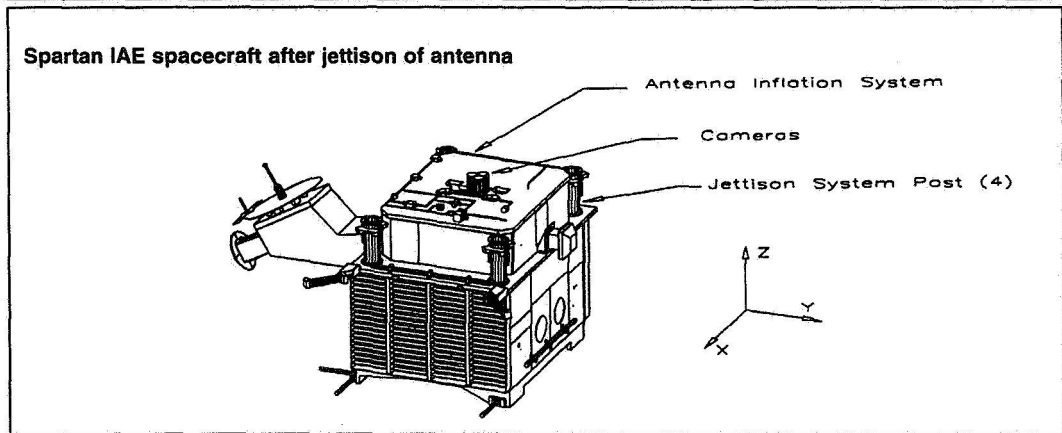
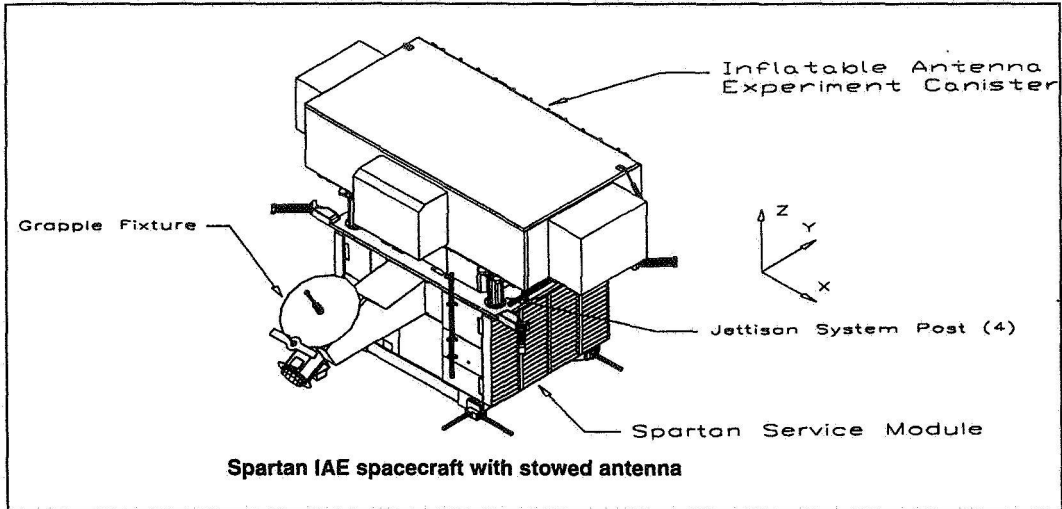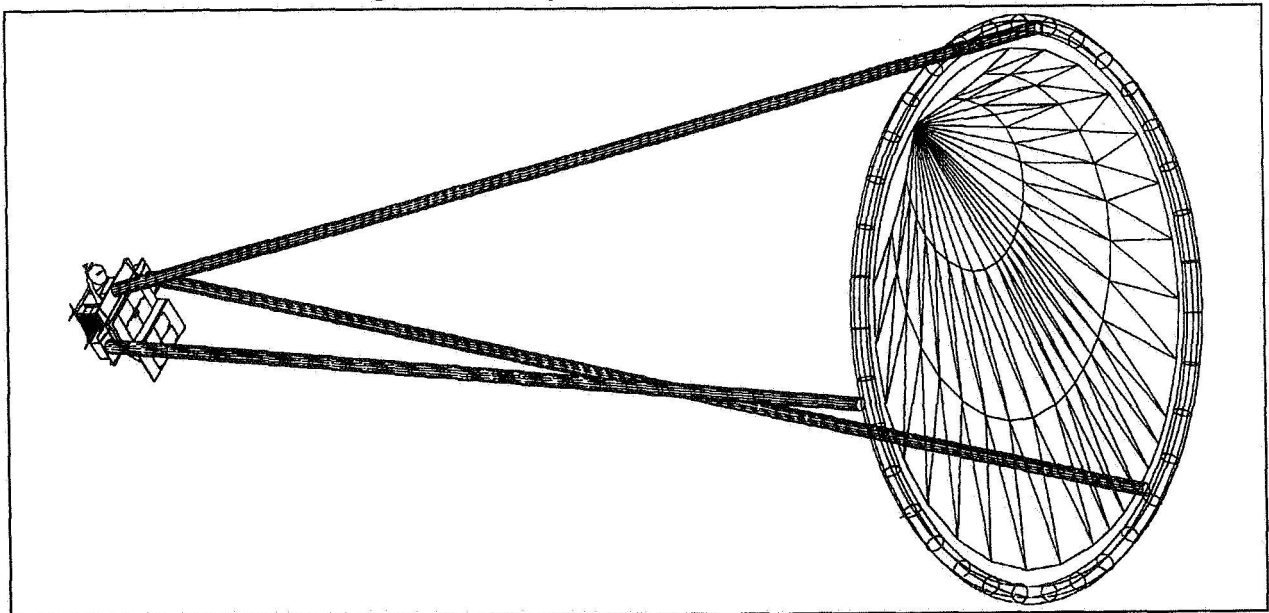**Spartan IAE spacecraft after jettison of antenna**

Figure 1. Spartan IAE Spacecraft
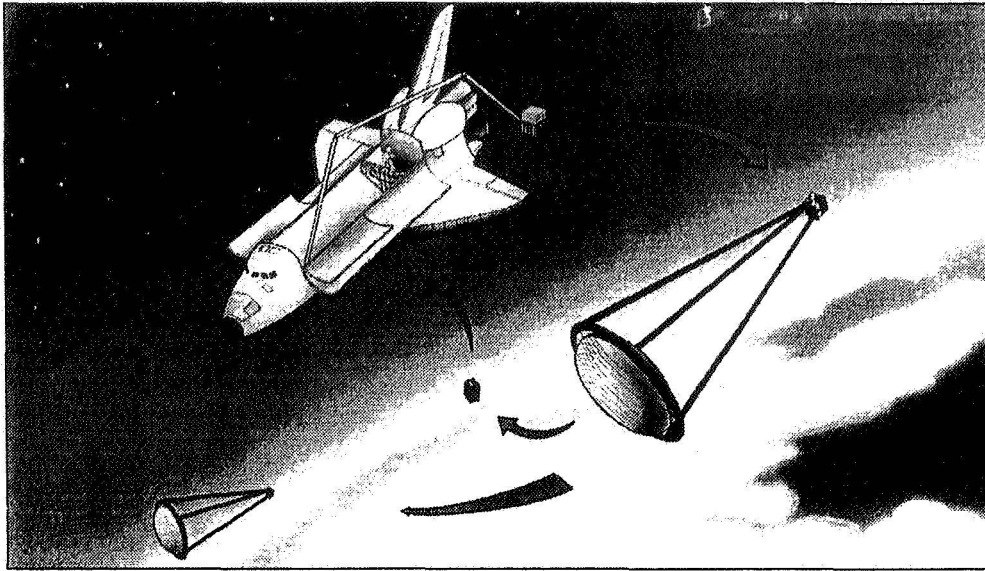


Figure 2. Spartan IAE with Antenna Inflated

**Figure 3. Spartan IAE Mission**

## Jettison System Design Requirements & Constraints

### Physical & Structural Accommodation

The jettison system has to serve as the structural interface between the Spartan carrier and the IAE canister. The characteristics of both items were fixed prior to the design of the jettison system. The jettison system has to provide an adequate load path with sufficient margins to allow for large uncertainties in the loading environment. A 22.86-cm (9-in) diameter footprint was determined to be available to accommodate each of the four jettison system posts, which are the interfaces between the IAE and the Spartan carrier.

### Jettison Performance

The system must separate the IAE from the spacecraft with low tipoff rates and with a proper separation velocity profile. Low tipoff rates are necessary to ensure that 1) the spacecraft and the jettisoned antenna do not come into contact during separation, and 2) the carrier spacecraft is stable for retrieval by the Shuttle. Contact between the parts in relative motion could potentially prevent successful separation. Spacecraft body rates must be within the attitude control system capability to null them. The separation velocity profile must be sufficient to separate the spacecraft and the antenna without imparting forces that could buckle the inflated antenna. A buckled antenna could become entangled with the spacecraft. Failure to meet these requirements could create a situation in which retrieval by the Shuttle would be impossible.

### Flight Safety

Inadvertent actuation of the jettison system, while either in the Shuttle bay or in close proximity to the Shuttle, is considered a catastrophic hazard to the Shuttle crew. Key to a successful jettison system was a design which provides adequate control of the hazard when integrated with the Spartan systems that control it.

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## Overall Jettison System Design

Preliminary design studies led to the selection of a pyrotechnically initiated Marman band system with coil springs providing the separation forces. The configuration of the Spartan carrier and the IAE dictated that four discrete attach points be simultaneously separated. The Marman band design provides both the high structural load carrying capacity and the required simultaneous separation action. A Marman band design was judged to be a reliable and inexpensive approach due to both its inherent simplicity and GSFC's extensive experience with Marman band separation systems. The major components of the jettison system design are the Marman band clamp/joint assembly, the pyrotechnic bolt cutter, the pushrod/spring assembly, and the structural posts (Figure 4).

A spacecraft mass properties summary and the structural design limit load factors are given in Tables 1 and 2, respectively. These parameters, along with the relatively small clearances between the jettisoned antenna assembly and the carrier spacecraft, drove the detailed design and testing of the jettison system.

| TABLE 1 SPARTAN IAE STRUCTURAL DESIGN LIMIT LOAD FACTORS | | | |
| --- | --- | --- | --- |
| | X Axis | Y Axis | Z Axis |
| TRANSLATIONAL, g | ± 4.5 | ± 3.5 | ± 9.8 |
| ROTATIONAL, rad/sec$^2$ | ± 26.2 | ± 65.2 | ± 33.7 |

| TABLE 2 SPARTAN IAE MASS PROPERTIES SUMMARY | | | |
| --- | --- | --- | --- |
| | WEIGHT (kg) | C.G. (X,Y,Z cm) | Ixx Iyy Izz (kg.-m$^2$) |
| Carrier Spacecraft | 847 | 63,-58,48 | 184, 150, 175 |
| IAE (inflated) | 329 | 76,-38, 836 | 47370, 47954, 4161 |

## Marman Band Design

The first Marman band design iteration for the IAE jettison posts consisted of a standard strip and shoe band, which could use either a guillotine cutter or an explosive bolt to release the band. Since the Shuttle program is sensitive to any kind of debris produced near a recoverable payload, the Marman band also required a catcher assembly. Due to the limited area in which the band had to fit and the correspondingly small size of the band and catcher components, the strip and shoe band design was abandoned. It was felt that a less costly and complicated design could be achieved by using a solid segmented aluminum band and a modular bolt cutter assembly which was mounted to the post and would be reusable after each firing. Similar band designs had been flown in the past by GSFC on numerous sounding rocket missions. This new smaller diameter band would incorporate many of the design features of the old sounding rocket bands.

Preliminary sizing of the post diameter, band diameter, and band separation bolt diameter were performed with design calculations using a conservative weight estimate of 363 kg (800 lbm) for the ejectable portion of the IAE and the loads in Table 1. A detailed discussion of both the methods used to size the Marman band and the correlation between the design analysis and the static pull test results are presented later in the paper.
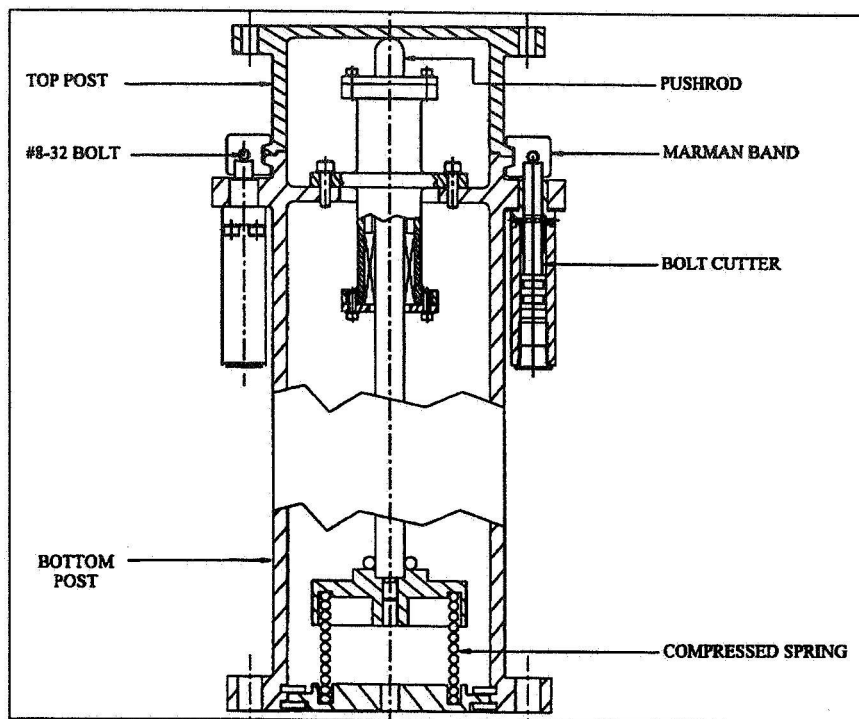
**Figure 4. IAE Jettison Post**

After determining the preliminary post loads from the design calculations, a mounting post and a solid segment Marman band were designed to fit within the available space. The IAE jettison post bands are constructed of a solid 7075-T73 aluminum ring, which has been cut into four equal segments. Each half of a band is linked and pinned together to create a flexible interface. The band halves interface to the post flanges with a 15° ramp angle and are pre-loaded with two #8-32 bolts, which rigidly clamp the top and bottom posts together (Figure 5). To preclude any type of bolt bending, the #8-32 bolts were seated into a bathtub-type fitting interface on hardened stainless steel swivel washers. Pre-load forces on the #8-32 bolts are provided by a bolt force sensor under the head of each separation bolt. Surface preparation of the bands consisted of hard anodizing the band segments and applying Braycote 601 to the band/flange interface before each installation.

After the separation bolts are cut by the bolt cutters, the band jumps off the interface flange and is retained by four catcher brackets, mounted to the bottom post. Each catcher bracket is connected to the band by a set of tension springs, which firmly hold the band to the bracket during the rest of the Spartan IAE mission and also during re-entry and landing of the Shuttle. Figure 6 shows the fully assembled jettison post.
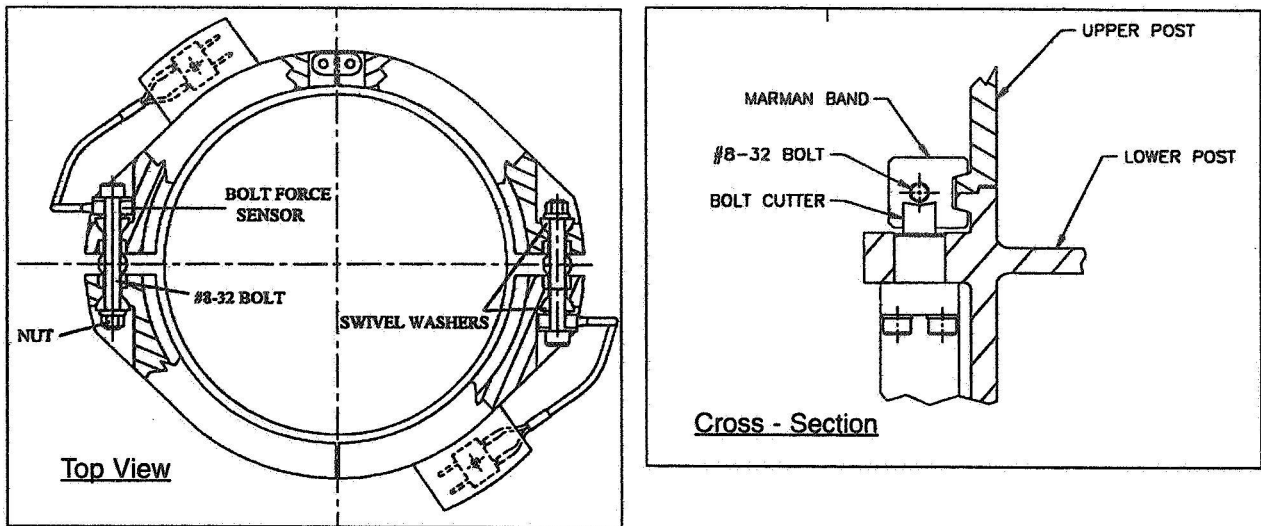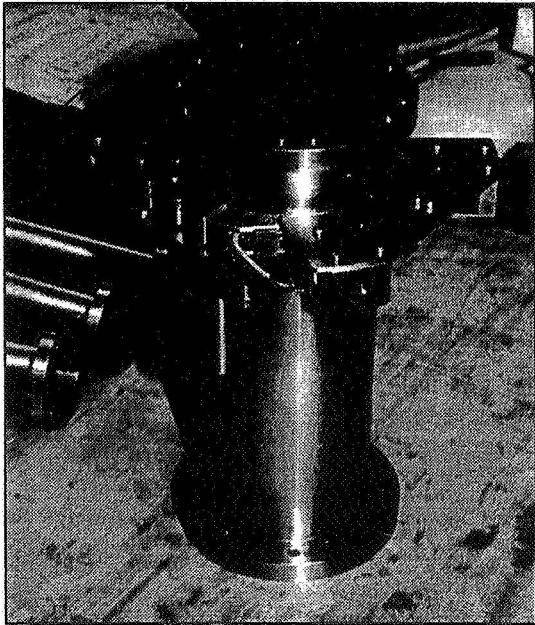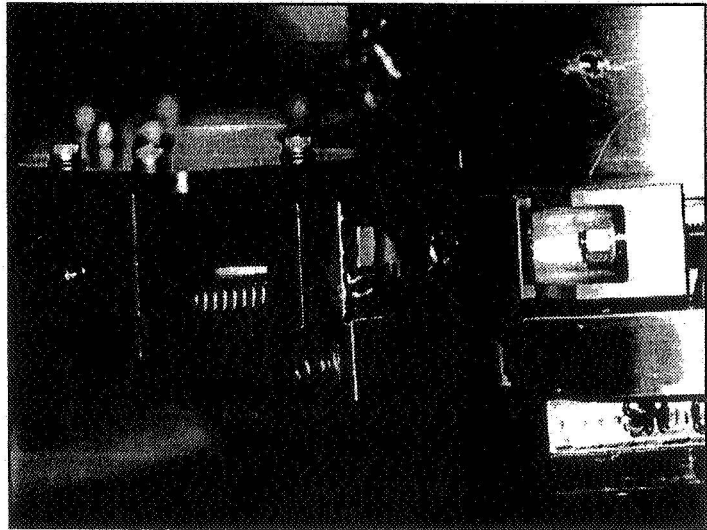
**Figure 5.   Solid Segment Marman Band**



Spartan 207/IAE Jettison Post

Close-up of the Marman Band Interface

**Figure 6.   Jettison Post Photos**

## Marman Band Analysis

A large number of different methods and formulas have been developed over the years to determine the required preload on a Marman band to prevent gapping at the ejection flange interface [3,4,5,6]. For this analysis, the following conservative relationship, which has been successfully used at GSFC in the past, was used [4]:

$$W = W_{axial} + W_{moment}$$

$$W_{axial} = \frac{F_{axial}}{\pi D}$$

$$W_{moment} = \frac{4M}{\pi D^2}$$

$$\text{Bolt Preload} = \frac{WD\,(\tan\beta - \mu)}{(1 + \mu\tan\beta)}$$

where: 
W = Line load around the band circumference
F = Maximum axial load at ejection interface {F = 21617 N (4860 lbf)}
M = Maximum moment at ejection interface {M = 1175 N-m (10,400 ft-lbf)}
D = Outside diameter of ejection interface flange {10.9 cm (4.3 in)}
b = Flange/band ramp angle (15°)
μ = Coefficient of friction (normally between 0.0 and 0.10)

A detailed flight loads analysis yielded the loads listed above. A coefficient of friction of 0.08 was assumed, and a required preload of 3781 N (850 lbf) was calculated. The application of a 1.4 factor of safety and a small allowance for measurement uncertainty resulted in a final bolt preload specification of 5782 N (1300 lbf), with a corresponding line load of 2856 N/cm (1631 lbf/in), which was higher than the preliminary sizing calculation. The only required change in the hardware to accommodate the higher loads was the screening and re-certification of the separation bolts to a higher level.

Comparison of this Marman band line load with the line loads of other Marman band designs [6] will show that this design can develop significantly higher line loads than most designs. This is possible because of the solid segment band strength and the small diameter and large wall thickness of the ejection post. On almost any other type of band design, these large line loads would almost certainly cause potential ring rolling problems at the flange interface. Even with the very stiff interface rings of this design, this large line load was a concern and was monitored during the pull test.

## Bolt Cutter Design

Release of the bands occurs when either one of a pair of redundant bolt cutters is actuated on each post. The bolt cutter assemblies are mounted to the bottom post and consist of an upper and lower housing, a bolt cutter blade, a crush washer, and a pressure cartridge. When the separation bolt is cut by the bolt cutter blade, the cutting force transferred by the blade is reacted by the band. This type of system can only be used in combination with a small separation bolt diameter (#8-32 or less will produce

a small cutting force) and a band which is rigid enough to react this cutting force back into the post flanges without adversely affecting the separation dynamics of the band. The bolt cutter is shown in Figure 7. This design has been successfully used on numerous sounding rocket missions.
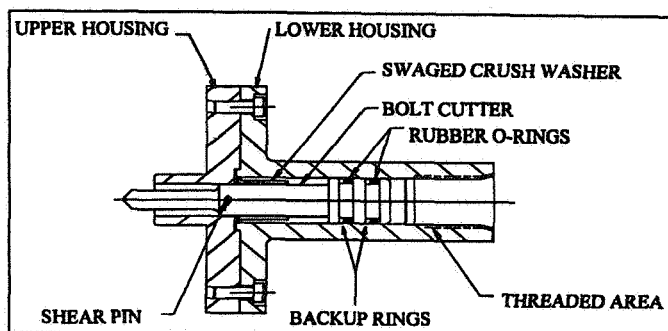


Figure 7. Bolt Cutter Assembly

Due to some of the previously mentioned limitations of this bolt cutter design, its acceptability for other applications will be limited; however, for this particular use, it has a number of desirable features. The upper and lower housings are made of high strength 15-5 stainless steel and can be disassembled, cleaned, and re-used after each firing. Due to the small amount of cutting force required, even the bolt cutter blades were re-used during functional testing after being re-sharpened. The modular design also allowed the bolt cutter assembly to be removed from the system without having to remove the band. The bolt cutter has proven to be simple to use, inexpensive, and very reliable.

## Pressure Cartridge

A Holex pressure cartridge, manufactured by Quantic Industries, was chosen to actuate the bolt cutter assembly. The cartridge is a fairly typical single bridge wire, 1.0-A "no-fire" and 4.0-A "all-fire" pressure cartridge. One of the primary reasons for choosing this cartridge is its previous use for the Hitchhiker program, and it had been qualified for flight on the Shuttle by GSFC.

The design and testing requirements for Shuttle pyrotechnics were reviewed and applied to this application. Shuttle pyrotechnic requirements are contained in NSTS 8060 Space Shuttle System Pyrotechnic Specification [7].

During the manufacturing and testing of the cartridges at Quantic, it was discovered that the Maximum Operating Pressure (MOP) of the bolt cutter assembly was high enough to yield the threads and o-ring cross-section of the CRES 302 pressure cartridge housing during the hydrostatic proof testing. Fortunately, for this application, the cartridge was significantly overcharged, so that the propellant charge could be reduced to achieve a pressure below the yield point of the cartridge body and still easily cut through the #8-32 bolt. This MOP proof test requirement in NSTS 8060 is very conservative when considering that the pressure load profile produced by a pressure cartridge firing is a very short transient load instead of the static pressure

load specified in the requirements. For this reason, it is strongly recommended that high pressure bolt cutter applications which must meet NSTS 8060 consider a higher strength housing material (Inconel 718 is common).

## Spring/Pushrod Design

After the bands are cut, the IAE is pushed away from the Spartan Service Module by four independent compression springs, located in each of the post assemblies. Each spring is guided by a pushrod, which rides in a linear bearing housing (Figure 4). The linear bearing housing and the pushrod provide a tightly controlled and guided stroke for the springs; however, the IAE and the Spartan Service Module are free to rotate with respect to each other during the jettison sequence. The spring design requirement was to provide enough force to push the inflated portion of the experiment away from the Spartan Service Module without buckling the struts of the antenna or without imparting angular rates into the Service Module greater than those allowed by the Spartan Attitude Control System. To verify the spring design, a dynamic analysis of the jettison sequence and of the subsequent velocity and rotational rates of the IAE and Spartan Service Module with respect to each other was performed. From the results of the dynamic analysis, it was found that a spring rate of 15 N/cm (8.5 lbf/in), with a stroke of 10.9 cm (4.3 in), would meet the desired requirements and also provide a separation velocity of approximately 0.93 m/s (25 in/s) between the Spartan Service Module and the inflated antenna.

## Jettison System Dynamic Modeling and Simulation

### Dynamic Analysis Overview
A dynamic simulation was required in order to understand quantitatively the relative motion between the Spartan carrier spacecraft and the IAE during the jettison. This was necessary to ensure that there will be no contact between the Spartan and the IAE, that the angular rate imparted to the Spartan spacecraft will be acceptable, and that the IAE struts will not buckle. The results of the dynamic analysis were used to develop specifications for the spring rates and minimum clearances between components.

A three-dimensional, rigid-body simulation of the jettison event for both the deployed and stowed IAE was performed using Automated Dynamic Analysis of Mechanical Systems (ADAMS) software. The center of gravity (CG) displacement time histories were the output from ADAMS and mapped to NASTRAN grid geometry, so that the minimal clearance between the critical IAE and Spartan geometry could be conveniently tracked at discrete locations. Parametric studies, involving variation of the plunger spring rates by ±10% and variation of the IAE CG location in the XY-plane, were included. The effect of the flexible IAE struts on the jettison event was also examined and found to be similar to the rigid simulations; therefore, only the rigid simulations are presented.

A total of twelve rigid body simulations were performed: three for the deployed and nine for the stowed configuration. The deployed cases consisted of nominal CG and plunger spring rates, along with two additional cases in which the CG and spring rates

were adjusted to produce maximum rotations about the X and Y axes. The stowed cases consisted of a nominal CG configuration, along with eight additional cases in which the CG was varied within the footprint of the four jettison posts.
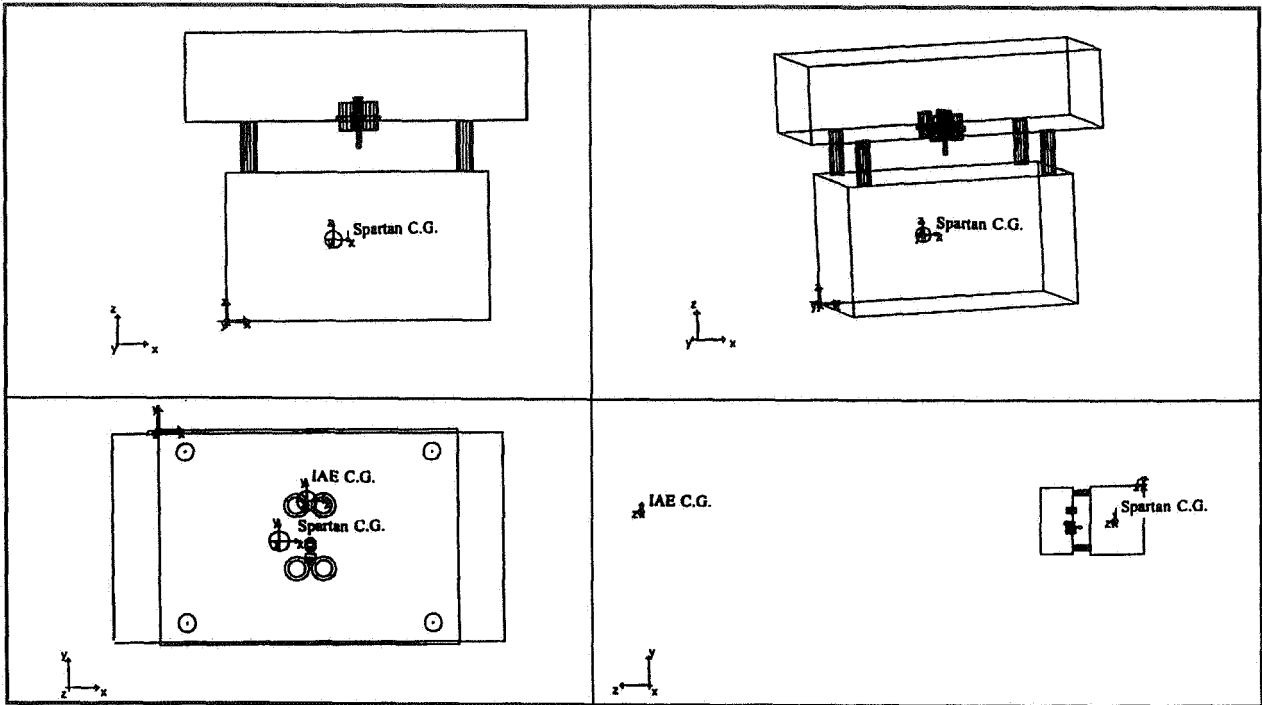


**Figure 8. Wireframe Rendering of ADAMS Model for Deployed Configuration**

## Dynamic Models and Analysis Procedure

The nominal deployed model consists of rigid masses located at the Spartan and IAE CGs. Table 2 contains the nominal mass properties for both the Spartan and IAE. Figure 8 shows a wireframe rendering of the deployed ADAMS model. The IAE CG is shown in the lower two figures, but not in the top two figures, because it is far above the main spacecraft body in the deployed configuration. The Spartan CG is located in the interior of the lower box. The spring housings, ejector housing, and camera are located at the bottom center of the upper box, which houses the stowed IAE antenna. An overhead view of these components is found in the lower left-hand figure. The four cylinders separating the Spartan and the IAE, shown in the upper right-hand figure, represent the jettison posts.

The jettison simulations were performed over a 0.75-second interval with a time step of 0.005 seconds. The IAE and Spartan CG displacements and Euler angles were the outputs from ADAMS for each configuration. The CG information was then mapped to NASTRAN model grid geometry, and the minimum clearance was calculated. The IAE and Spartan CG rates were also tracked. Using the CG rates, jettison spring displacements, and mass properties of the system, an energy check was performed on the deployed nominal run. At each of the 100 time steps, from 0.00 to 0.50 seconds, the potential energy in the springs and the kinetic energy of the IAE and Spartan were

calculated. The sum of the energies remained constant throughout the analysis. Figure 9 shows plots of the potential, kinetic, and total energy in the system, as well as a typical jettison spring force profile.
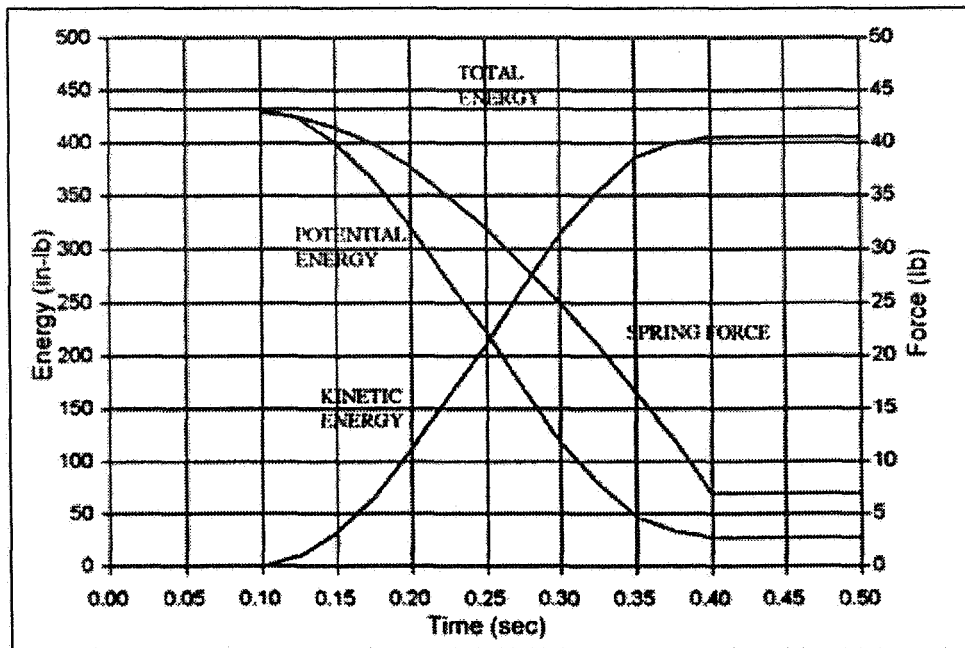


**Figure 9. System Energy for Nominal Deployed Configuration**

## Dynamic Analysis Results

Table 3 summarizes the results of the rigid body simulations. A positive clearance was obtained for all simulations, with a minimum clearance of 0.23 cm (0.09 in) for a worst-case stowed configuration. Also, the angular rate predicted for the Spartan is well within the ACS bounds, and the forces imparted to the IAE were found to be well within the allowable buckling for the struts. Therefore, the results of the analysis show that all the requirements for successful jettison have been satisfied, thus validating the jettison system design and allowing the specification of final spring rates.

## Jettison Post Functional Testing

A great deal of important information was learned about the characteristics of a solid segment band during the initial functional testing of the Engineering Test Unit jettison post. As with any Marman band, it is very important to achieve consistent repeatability when installing and pre-loading the band. This was achieved here by using a detailed installation procedure and incremental monitoring of the bolt force with the bolt force sensors, the torque values, and the gap between the cutter blade and the bathtub fitting on the band. On a couple of occasions, when one of these values began to stray outside of previous average values, the band was disassembled only to find a small amount of debris on the interface or a rotational misalignment of the band with respect to the cutter assembly.

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| | | Minimum clearance (in) | Steady State Translational Velocity (in/sec) | | Maximum Angular Rates (deg/sec) | | | |
|---|---|---|---|---|---|---|---|---|
| **Table 3 - Results of Jettison Simulations for the Deployed and Stowed Rigid IAE** | | | | | | | | |
| | | | IAE | Spartan | IAE | | Spartan | |
| | | | Z | Z | Rx | Ry | Rx | Ry |
| Deployed: | Nominal | 0.24 | 17.54 | -6.81 | -0.031 | -0.004 | -0.624 | 6.125 |
| | Max Theta-X | 0.25 | 17.54 | -6.81 | 0.083 | -0.004 | 1.088 | 6.159 |
| | Max Theta-Y | 0.06 | 17.37 | -6.74 | -0.033 | 0.169 | -0.624 | 9.409 |
| Stowed: | Nominal | 0.40 | 17.74 | -6.82 | 0.25 | -5.10 | -0.66 | 5.67 |
| | CG (worst case) | 0.09 | 14.57 | -5.58 | -0.13 | 20.81 | -0.45 | 10.88 |

\* All minimum clearances are between the spring housings and the inflation panel.

During the first single bolt cutter functional test, two problems with the system were discovered. The first problem had to do with the flexibility of the band. Although the first functional test was successful, which is to say that a single bolt was cut, the band was released, and the top post was ejected. It was obvious that the band was not as flexible as we would like and that there was potential for it to become hung up on the top post or in some way interfere with the ejection sequence. A simple solution to this problem was implemented by attaching a slider mechanism to the band, thus allowing the springs of the catcher assembly to move relative to the band during release. This provided more flexibility to the system and let the band move further from the post flanges after release.

The second problem had to do with bolt cutter blade and how it was cutting through the #8-32 separation bolt. In the past, on similar solid segment sounding rocket bands, a heat-treated 4140 alloy steel cutting blade, with a cutting angle of 90°, was used to cut through a single or double #6-32 separation bolt interface. Increasing the bolt diameter by 0.076 cm (0.030 in), to a #8-32, for this system was not perceived as a problem. During the first functional tests, however, it was found that this combination of bolt diameter, bolt material, cutter angle, and cutter material caused the bolt to fail on two planes instead of one. This produced a very consistent 0.25-cm (0.10-in) long bolt section to be punched out. The creation of debris raises safety concerns on Shuttle payloads, thus this was a potentially serious problem.

Close examination of the bolt failure planes clearly showed signs of shear failure across both planes. A comparison of the hardness of the cutter material and the bolt material showed very similar values of about 40 Rc. From this information, in combination with the large cutter angle (90°) and the deformation observed on the sharp point of the cutter, it was concluded that the cutter angle was too large and the cutter material was not hard enough to achieve the initial cutting depth required to fail the bolt on a single plane. To solve this problem, a new cutter blade was designed with a smaller cutting angle of 60° and made of a high strength/hardness alloy steel,
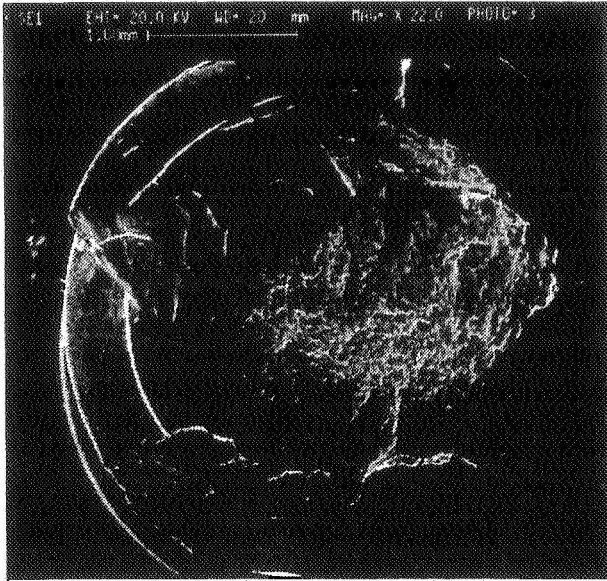
called AeroMet 100. AeroMet 100 combines high strength and hardness properties (50–54 Rc) with good ductility values and corrosion resistance. To achieve these properties, a costly and involved heat treating process must be performed; however, for our application, this turned out to be a very successful choice. The AeroMet 100 cuts through the bolt cleanly on a single plane and is so tough that, during functional testing, the cutters are being re-used after each firing after only a small amount of re-grinding on the sharp edge. Figure 10 shows magnified photos of the bolt cross-sections before and after the cutter modification.
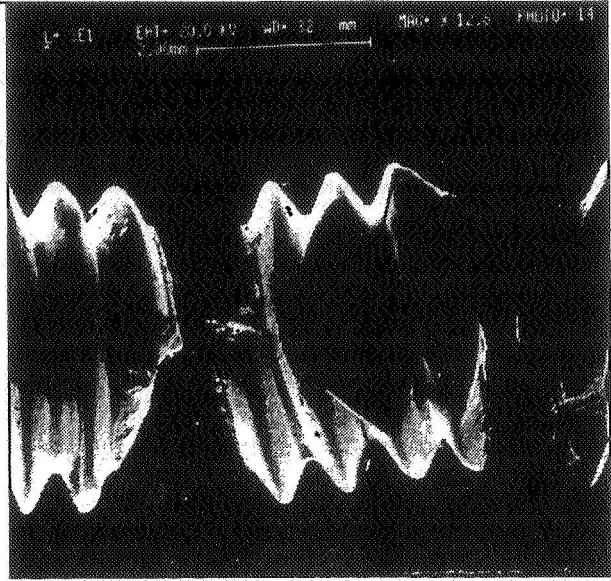
## Jettison Post Static Load Pull Testing

The post was subjected to two pulls initially, both at an angle of 64° and a force of 33805 N (7600 lbf). The first pull was across one of the band bolts, and the other pull was across one of the Marman band links. These two angled pulls qualified the post to the Spartan design load levels, with the additional factor of 1.4. Following the second test, the post was removed and taken to another site to be functionally tested. After the functional test, the post was re-assembled and returned to the test site and pulled two additional times. These final pulls were overload tests to see if the band could be forced to gap with either a horizontal or vertical pull force. Data from these last two pull tests provides insight into the strength of the post/band interface. The pulls are summarized below:

      Test 1 - Pull at an angle of 64° with a force of 33805 N (7600 lbf) across
            band bolt #2.
      Test 2 - Pull at an angle of 64° with a force of 33805 N (7600 lbf) across
            one of the links.
      Test 3 - Pull vertically until the band interface gaps.
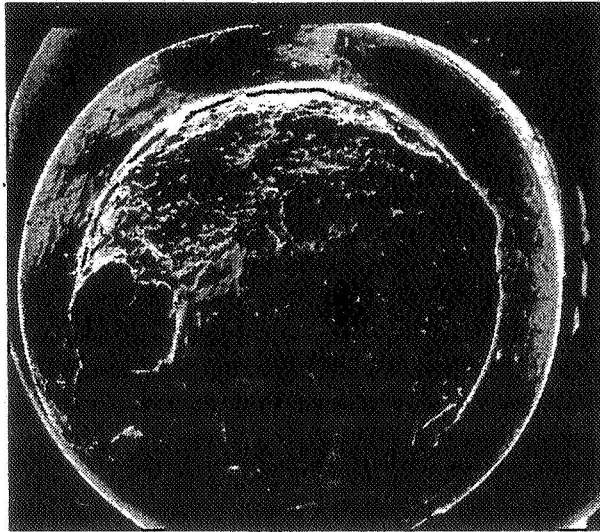      Test 4 - Pull horizontally until the band interface gaps.

Based on the results from the first two qualification pulls, it was determined that the Marman band interface did not gap. Figure 11 shows the stress readings at three locations (gages #1, #2, and #3 are inside the post at the flange; gages #4, #5, and #6 are on top of the Marman band; and gages #7, #8, and #9 are on the back face of the Marman band) as a function of the pull load. Figure 12 shows the bolt forces over the same load increments. Previous testing of Marman bands at GSFC has shown that, when gapping occurs at the band interface, the clamping strain energy associated with the bolt pre-load was relieved, and the Marman band and bolts began to take the entire load. This was displayed by a marked increase in the bolt loads, as well as increased hoop stresses in the band. Neither of these phenomenons occurred in the first two tests for the IAE jettison post. As an additional indicator of gapping, LVDTs were added at the band interface to measure any sudden change in deflection which might occur during the test. Again, the data showed negligible changes for the first two qualification pulls. Also, strain gauges located on the inside surface of the post diameter at the ejection/ flange interface showed fairly low stresses, which removed any worries of ring rolling occurring at the flanges due to the large line load in the band (Figure 11).

Cross section created by original cutter blade

Bolt debris created by original cutter blade (note three sections)

Cross section created by redesigned cutter blade

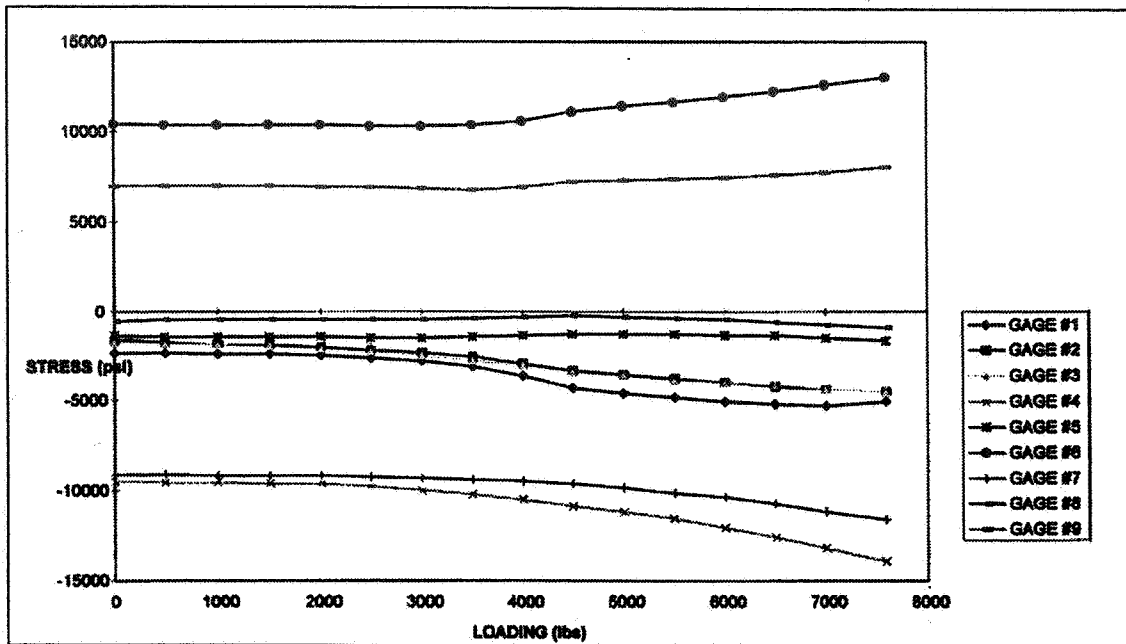Figure 10.  Magnified Photos of Cut Separation Bolts
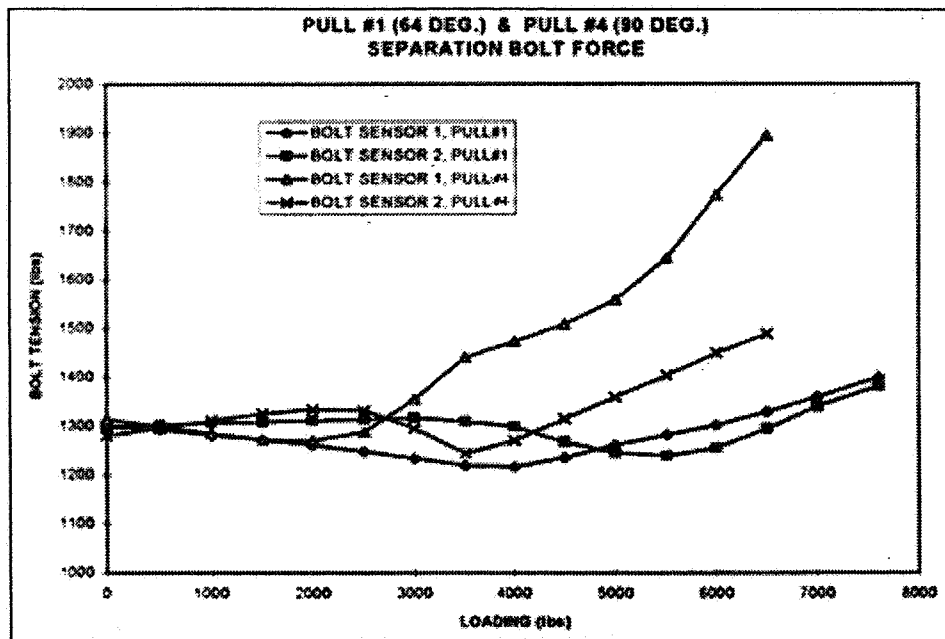
**Figure 11. Stress Data Pull Test #1**



**Figure 12. Bolt Force Data Pull Test #1**

The most interesting results from the two overload tests occurred in the horizontal pull of test 4. Test 4 applied up to a 3853-N-m (34125-in-lbf) bending moment at the Marman band interface by pulling at 90° to the axis of the post with a load of 28912 N (6500 lbf). This is equivalent to a moment load which was three times higher than the maximum moment produced using the design limit loads. The purpose of this test was to determine at what bending load the post would either gap or reach the maximum allowable bolt force sensor readings. Based on the test plan, the loading stopped

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when the bolt loads reached 8006 N (1800 lbf), which is the proof load level of the separation bolts. At this level, the stress and bolt force sensor data still did not conclusively suggest any gapping (Figure 12).

The results of the pull testing showed that the solid segment band is very strong and showed good correlation between analytical predictions and the measured bolt force and band hoop stress. Also, the results of test 4 showed that the frictional interface between the post flanges was not broken, even with a shear load of 28912 N (6500 lbf). This was a direct and positive result of the high line load in the band. The two functional tests performed after the pull tests were successful.

The results of the static pull tests were also used to specify a variable cross-section beam representation of the jettison posts in the spacecraft finite element model. The stiffness properties of the post, above and below the band interface, were determined using deflection data from the pull test. In this way, the flexibility of the Marman band joint was taken into account in the finite element model.

## Simulated Deployment Testing of the Jettison System

To test functionally the ejection system (all four jettison posts together) before flight, a Mass Deployment Simulator (MDS) was designed to simulate both the mass and the interface between the posts and the ejectable portion of the payload. This includes the actual flight electrical connections between the inflation panel and the experiment. These connectors are designed as rack and panel, spring-loaded, zero-force disconnect connectors. In addition to simulating the mass of the experiment under zero-g, the MDS is capable of enveloping a wide range of X-Y CGs and introducing a simulated thermal deflection in two of the jettison posts.

The simulator consists of a frame and weight assembly, which equals the weight of the ejectable portion of the IAE payload. To offset the effect of gravity, a balance weight is connected with wire rope across pulleys to the MDS (Figure 13). The X-Y CG of the MDS is adjustable by moving ballast weights and shifting the lift point accordingly. The lifting ball can be adjusted 7.6 cm (3 in) in the Z direction to account for the shifting/stacking of the ballast weights. Together, they provide the capability of testing the ejection system under a wide range of CG locations. Four tests using the MDS were planned. In all cases, only one pressure cartridge per post was planned to be fired.

> Test 1 - CG located at the center of the post pattern with no IAE electrical connectors included.
> Test 2 - CG located at the center of the post pattern with the IAE electrical connectors mounted in the system.

Test 3 -CG located at the nominal IAE deployed location with an
additional offset of 25% and the IAE electrical connectors
mounted in the system.

Test 4 - CG. located 100% off the nominal IAE deployed location, two
posts with a simulated thermal deflection of 0.10 in, and the IAE
electrical connectors mounted in the system with an undersized
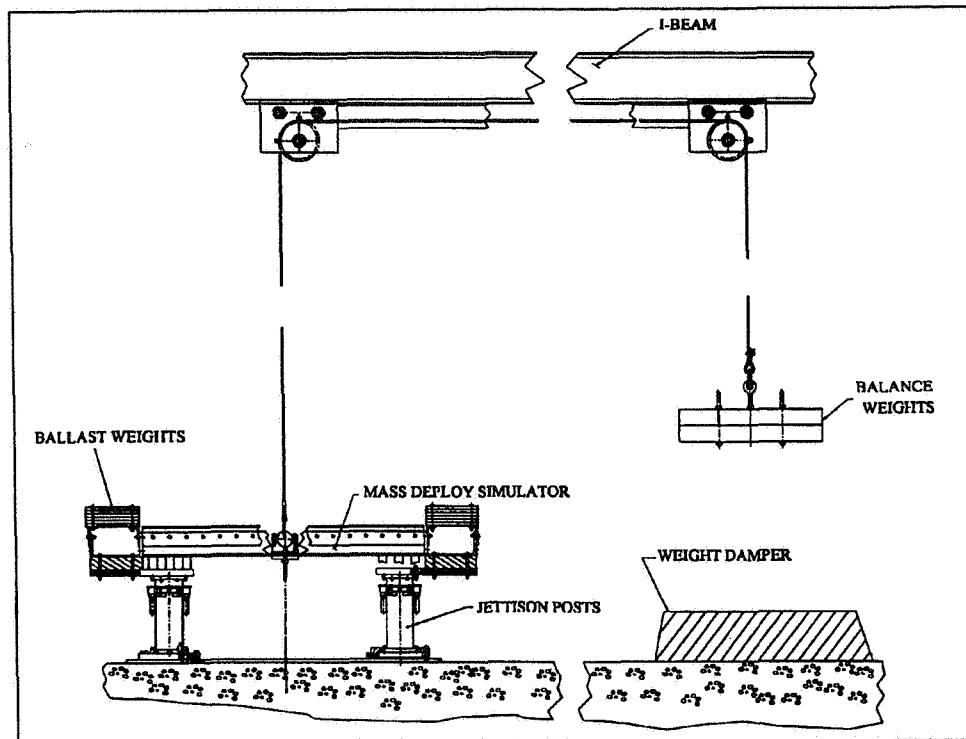spring force.



**Figure 13.   Mass Deploy Simulator**

As of the writing of this paper, the first three of the four tests using the MDS have been
performed.  In each test, the jettison posts have performed nominally without a single
anomaly or problem.  Due to budget and schedule constraints, the last test will most
likely not be performed; however, the results of the first three tests have given us a
high degree of confidence in the design approach.

## Conclusion

The Spartan IAE mission is manifested on STS-77 in May of 1996.  The jettison
system has been subjected to extensive testing and evaluation with highly successful
results.  It has proven that the use of multiple small Marman band clamps to separate
large objects in space is a viable design approach.  Furthermore, the combination of a
strong solid segment band with a modular reusable bolt cutter assembly has shown,
for this application, to be inexpensive, reliable, and able to carry the high structural
load levels required by the Shuttle.

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