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Development of the Weapon Borne Sensor Parachute System

Vance L. Behr

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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DEVELOPMENT OF THE WEAPON BORNE SENSOR PARACHUTE SYSTEM

Vance L. Behr
Unsteady and Reactive Fluid Mechanics Department
Sandia National Laboratories
Albuquerque, NM 87185-0836

ABSTRACT

A parachute system was designed and prototypes built to deploy a telemetry package behind an earth-penetrating weapon just before impact. The parachute was designed to slow the 10-lb telemetry package and wire connecting it to the penetrator to 50 fps before impact occurred. The parachute system was designed to utilize a 1.3-ft-dia cross pilot parachute and a 10.8-ft-dia main parachute. A computer code normally used to model the deployment of suspension lines from a packed parachute system was modified to model the deployment of wire from the weapon forebody. Results of the design calculations are presented. Two flight tests of the WBS were conducted, but initiation of parachute deployment did not occur in either of the tests due to difficulties with other components. Thus, the trajectory calculations could not be verified with data. Draft drawings of the major components of the parachute system are presented.

ACKNOWLEDGEMENTS

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CONTENTS

NOMENCLATURE

$B.S._{s.l.}$	Minimum required breaking strength of a suspension line
$C_D S$	Nominal full open drag area of the parachute
C_X	Parachute opening shock factor (or added mass factor)
d_{fill}	Filling distance of a parachute canopy
$D.F.$	Design Factor to ensure adequate safety margins in the design
D_p	Flying diameter of the parachute canopy
E_{spring}	Energy stored in the tail cone ejection springs
F_{drag}	Drag force
$F_{friction}$	Force required to break the wire free from the packed configuration (friction and mold release forces included)
$F_{inertia}$	Force due to the inertial loads of the wire
$F_{\max}$	Maximum expected load
k	Spring constant of an individual tail cone ejection spring
$\dot{m}$	Rate at which mass is being picked up by the parachute while spooling from the dispenser
$m_{tail-cone}$	Mass of the tail-cone
$M.S.$	Margin of Safety
n_{fill}	Filling constant for a parachute canopy
$n_{s.l.}$	Number of suspension lines
$n_{springs}$	Number of tail cone ejection springs
q_{deploy}	Dynamic pressure
t_c	Minimum required fabric strength (force/unit length)
V	Velocity of the parachute
$V_{tail-cone}$	Velocity of the tail-cone
ΔV	Velocity change imparted to the wire as it leaves the dispenser
W_{TM}	Weight of the TM package
W_{wire}	Weight of the deployed wire
x	Amount the tail cone ejection springs are compressed
X_1	Force reduction factor
r_{air}	Density of the air
r_{wire}	Linear density of the wire

INTRODUCTION

This report documents the development of a parachute system for the Weapon Borne Sensor program. This effort was undertaken on behalf of the Air Force as an Advanced Concept Technology Demonstration within the Counter Proliferation Initiative. The funding agency was the Air Force Wright Laboratory Armament Directorate located at Eglin AFB, Florida.

The concept of the WBS program is to develop an enhanced conventional penetrator that uses a parachute-deployed transmitter to convey information back to the delivery aircraft about the nature of the impact/penetration. By deploying a parachute just before impact that decelerates a telemetry package connected to the penetrator by a spooling wire, accelerometer data can be transmitted back for evaluation. One of the challenges of such a system is designing a spooling wire system that can function at wire-dispensing speeds of ~900 fps and a wire that will remain intact in the hole left behind the penetrator to meaningful penetration depths. An important factor that influences wire survivability is the velocity of the wire relative to the surrounding walls of the penetration hole. The wire velocity is determined by the sizing of the parachute system.

WEAPON BORNE SYSTEM OVERVIEW

The Weapon Borne System (WBS) is targeted at providing real time data on target structure. This data includes number of concrete, air void, and soil layers penetrated and location and/or time of detonation. Being an Advanced Concept Technology Demonstrator (ACTD) program, the system is envisioned to integrate mature technologies in a minimum of developmental tests and with a number of units remaining as a residual capability. Because of this requirement the WBS was designed to interface with the existing BLU-109, 2000-lbm penetrator and the GBU-24 tail kit with no or minimal modifications.

The system is comprised of an accelerometer sensor subsystem, a spooling wire subsystem, a telemetry and power (TM) subsystem, a parachute subsystem, a proximity sensor/initiation subsystem and all the integrating hardware. The entire WBS is shown schematically in cross section in Figure 1. The accelerometer subsystem is mounted intimately on the aft bulkhead of the BLU-109. The wire dispenser is mounted just aft of the accelerometer subsystem and contains over 700 ft of multi-conductor cable that allows the accelerometer subsystem to communicate with and receive power from the TM subsystem. A tube located within the void space in the center of the GBU-24 tail kit houses the TM and parachute subsystems. The proximity sensor is located at the far aft end of the fin kit. A dome cover on the tail is equipped to be released and propelled into the trailing air stream by springs and explosive bolts and is hereafter referred to in this report as the "tail cone."

The system integrator for the WBS was the Albuquerque office of Applied Research Associates (ARA). ARA was also responsible for the wire dispenser and tail cone ejection system. The Wright Laboratory/Armament Directorate at Eglin AFB, FL, designed the accelerometer and TM systems. The Army Research Development and Engineering Command (ARDEC) designed the proximity sensor. Personnel from the Unsteady and Reactive Fluid Mechanics Department 9116 of Sandia National Laboratories designed the parachute system.

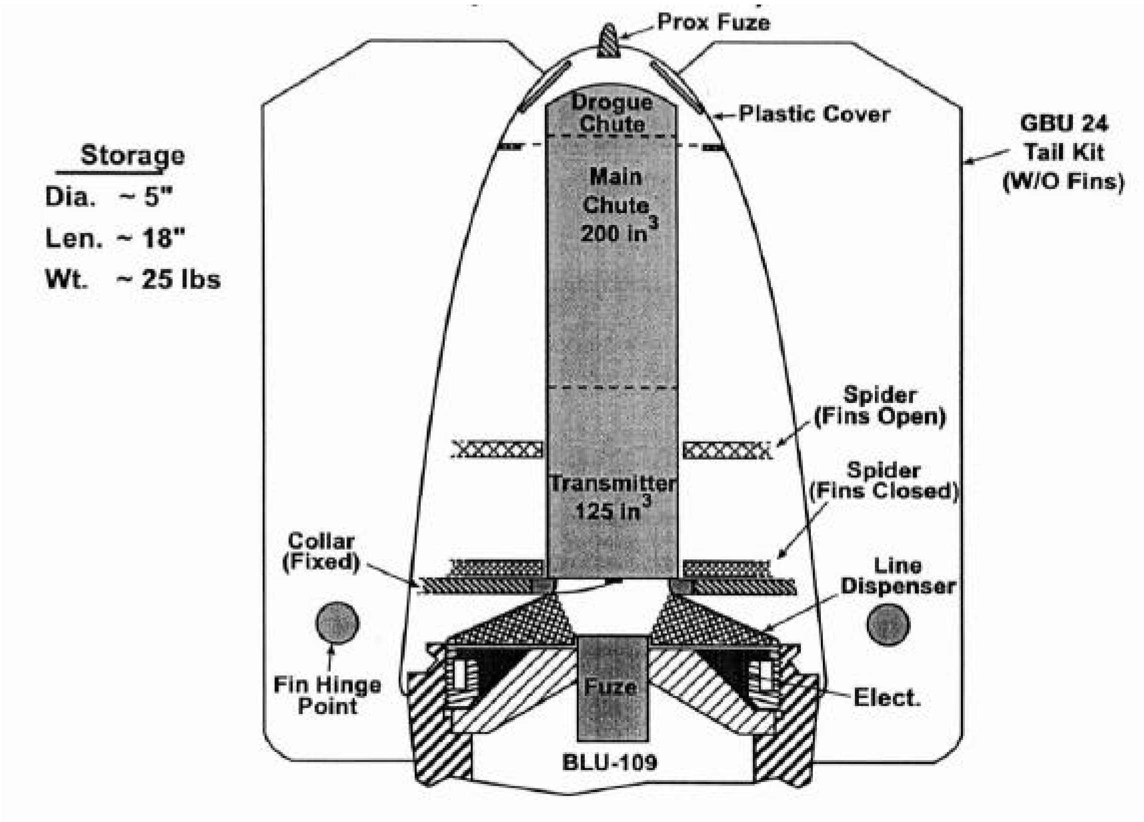


Figure 1. Schematic side view of WBS system components in GBU-24 tail kit.

SYSTEM REQUIREMENTS

The requirements for the parachute system were initially specified, but considered to be negotiable, within limits, recognizing that the initial specifications may have conflicted with one another. The initial specifications were as follows:

Deploy a telemetry (TM) package from the aft end of a GBU-24 during flight.

Be fully deployed in 0.15 sec.

Reduce total velocity of TM package from 800-1000 fps to < 100 fps.

Deceleration should occur within 400 ft.

Weight of TM package and signal wire (when fully deployed) ~25 lbs.

Parachute pack volume 200 in^3 (4.8 in. dia. X 11 in. long).

As the program progressed, some of these specifications changed and more were added:

Parachute pack volume was reduced by the amount required to accommodate a blade antenna on top of the TM package.

Maximum deployed wire at time of impact increased to 600 ft.

Maximum TM acceleration of 365 g's was accepted.

Desired to have wire velocity w/r/t ground <50 fps.

Provisions needed to be made for routing a ribbon cable through the parachute compartment.

The original requirements of being deployed in 0.15 sec of deceleration in 400 ft was deleted in favor of the requirement on maximum amount of deployed wire.

The combined weight of the TM package and wire was reduced to 13 lbs.

Based upon the revised set of requirements, a parachute system was designed using the tail cone to deploy a pilot parachute that deployed a main parachute for the deceleration of the TM package and deployment of the wire.

SYSTEM DESIGN

Sizing of the parachutes was done in stages. First the main parachute was sized. This then allowed an estimate to be made of the main parachute weight, a parameter required for the sizing of a pilot parachute.

Main Parachute

An initial estimate of the main parachute size was calculated from basic drag equations for parachutes using steady state values for the descent velocity and wire strip out force. As the main parachute design firmed up, a computer code was used to obtain more accurate timing information and to estimate the peak loads in a dynamic environment.

The force required of the main parachute can be broken into individual components as follows:

$$F_{drag} = F_{inertia} + F_{friction} + W_{wire} + W_{TM} \tag{1}$$

where:

F_{drag} is the required steady state drag force,

$F_{inertia}$ is the force required due to the inertial loads of the wire,

$F_{friction}$ is the force required break the wire free from the packed configuration (friction and mold release included),

W_{wire} is the weight of the deployed wire, and

W_{TM} is the weight of the TM package.

The main parachute was originally sized using a descent velocity of 40 fps and estimates of the TM package weight (15 lbs) and the inertial and friction forces of dispensing the wire (10 lbs.). Based upon this, a required drag area of approximately 15 ft^2 was calculated. However, as the problem was analyzed more carefully, it was learned that the inertial loads of deploying the wire drive the size of the parachute more than the weight of the TM package.

Using the conservation of momentum, the force required by the parachute to deploy the wire can be written as follows:

$$F_{inertia} = \dot{m}\Delta V \tag{2}$$

where:

$\dot{m}$ is the rate at which mass is being picked up by the parachute while spooling wire from the dispenser, and

ΔV is the velocity change imparted to the wire as it leaves the dispenser.

The rate of mass addition of the wire can be related to the mass per unit length of the wire, r_{wire}, and the velocity change imparted to the wire such that equation (2) becomes:

$$F_{inertia} = r_{wire} (\Delta V)^2 \tag{3}$$

The drag area required to produce a given amount of force, at a specified steady parachute velocity can be calculated as:

$$C_D S = \frac{F_{drag}}{\frac{1}{2} r_{air} V^2} \tag{4}$$

where:

$C_D S$ is the required drag area,
r_{air} is the density of the air, and
V is the velocity of the parachute.

Initial estimates for the wire density were 6 lbm/1000 ft. Using this density and a differential velocity of 960 fps (penetrator velocity of 1000 fps and a steady state wire velocity of 40 fps), the drag force required by the parachute just to overcome inertial effects is approximately 100 lbf. Adding to this a 17.5 lbf estimate of the weight of the TM package and wire (fully deployed) and an estimate of 10 lbf for friction, yielded a drag area requirement of 107 ft^2. Later more refined estimates of TM weight (10 lbf) and wire density (4.1 lbm/1000 ft) led to a revised estimate of required drag area of 63.9 ft^2.

Past experience with some prior programs that utilized a wire dispenser indicated that the inertial loads would only be half that as dictated by equation (3). Using that in Equations (1) and (4) yields a required drag area for the parachute of 32 ft^2. Unfortunately, this results in a very large discrepancy in drag area. Sizing the parachute too small would result in an excessive wire velocity relative to the ground. Too large of a parachute would result in deploying all of the wire before the penetrator impacted the ground. As a compromise the two estimates were averaged, resulting in a required drag area of 48 ft^2.

Various types of parachutes could be used to achieve this drag area. Given the difficulties in and the short times available for the receiving aircraft to lock onto the transmitted signal, it seemed prudent to utilize a parachute type that demonstrates very stable behavior. It also seemed prudent to select a design that was simple and hence inexpensive to fabricate. While guide surface parachutes are very stable, they are costly to build. Flat circular or conical solids are relatively easy to build but typically demonstrate oscillatory behavior during descent. A cross (or cruciform) parachute is both simple to build and, if designed properly, very stable. Thus, a cross parachute was chosen for the main parachute design.

A cross parachute typically has a drag coefficient in the range of 0.6-0.85.[1] Using a drag coefficient of 0.8, the desired drag area of 48 ft^2 dictates a 10.8-ft-dia cross parachute. Knowing the size of the parachute, the dynamic pressure at the time of deployment, and the payload weight, an initial estimate of the maximum load can be made using the following equation.

$$F_{max} = q_{deploy}(C_D S)C_X X_1 \tag{5}$$

where:

F_{max}	is the maximum expected load,
q_{deploy}	is the dynamic pressure at the time of deployment initiation,
$C_D S$	is the nominal full open drag area of the parachute,
C_X	is the opening shock factor, and
X_1	is a force reduction factor.

The opening shock factor (or added mass factor) is used to account for dynamic loads that result from the initial inrush of air and its momentum when a canopy initially opens. It is an empirically derived coefficient and is usually considered to be constant for a given parachute type. For a cross parachute it is usually in the range of 1.1-1.2.[1]

The force reduction factor is used to account for the fact that during the canopy inflation process, the payload is itself slowing down due to the drag produced by the canopy. Thus, by the time the canopy has reached full open status, the velocity, and hence the dynamic pressure, has already diminished from what existed at the beginning of the inflation process. This factor is determined empirically and is based upon the ratio of included mass in the canopy and the payload mass. In the case of the WBS parachute and payload, the force reduction factor is quite significant, something less than 0.1.

For lightly loaded, unreefed canopies, such as the WBS parachute, convention is to disregard the opening shock factor[2]. In order to be conservative, a force reduction factor of 0.1 was assumed. The nominal delivery velocity of 900 fps at sea level conditions yields a dynamic pressure of 963 psf. Using these values a maximum deployment force for the main parachute is calculated to be 4622 lbf.

With the maximum force known, simple membrane theory can be used to estimate the required fabric strength for the canopy. By assuming the canopy inflates in a spherical shape and that the maximum force occurs at the time of maximum flying diameter (a very conservative assumption in this case of very low mass ratios), the following equation can be used:

$$t_c = \frac{F_{max}}{pD_p}(D.F.) \tag{6}$$

where:

t_c is the minimum required fabric strength (force/unit width),
D_p is the flying diameter of the parachute canopy, and
$D.F.$ is the appropriate design factor to ensure adequate safety margins in the design.

A 10.8-ft-dia cross parachute will fly at a maximum diameter of approximately 5.8 ft. A typical design factor for single use parachutes in ordnance applications is 2.2. Using these values and the previously calculated maximum force, yields a minimum required fabric strength of 47 lbf/in. This allows the use of 2.25oz/yd^2 MIL-C-7350, Type I, nylon canopy cloth that has a rated strength of 90 lbf/in.

The suspension lines can be sized based upon the maximum force, the number of lines and a design factor as well. This relationship can be written as:

$$B.S._{s.l.} = \frac{F_{\max}}{n_{s.l.}}(D.F.) \tag{7}$$

where:

$B.S._{s.l.}$ is the minimum required breaking strength of a suspension line, and
$n_{s.l.}$ is the number of suspension lines.

Choosing five lines per panel on the cross parachute results in a total of 20 suspension lines and ensures an intersection of lines at the very apex of the canopy. This intersection allows for a centered attachment point for a vent break cord for the main parachute. Using the same design factor of 2.2, results in a minimum required suspension line strength of 508 lbf. This allows the use of MIL-C-7515, Type II, nylon cord (a very common material) with a 550 lbf breaking strength (lb-brkg-str) for suspension lines.

Given the material selection, the actual margins of safety (*M.S.*) can be calculated as:

$$M.S. = \frac{(Actual\ Strength) - (Minimum\ Required\ Strength)}{(Minimum\ Required\ Strength)} \tag{8}$$

This results in margins of safety of 0.9 and 0.1 for the canopy cloth and suspension lines, respectively.

The full details of the construction of the main canopy can be found on draft drawings included as Appendix A. The initial estimate of the weight of the main parachute was 2.2 lbm for the canopy and 1.1 lbm for the suspension lines for a total weight of 3.3 lbm.

Pilot Parachute

In order to keep bag strip velocities for the main parachute manageable (<400 fps), the drag area for the pilot parachute was chosen to be 0.9 ft^2. Once again for stability and ease of manufacture, a cross parachute design was chosen for the pilot parachute. A 19-inch-diameter cross parachute is required to generate the desired drag area.

Using the same process as outlined previously for the main parachute, the maximum force for the pilot parachute was calculated to be 312 lbf. For this load and an inflated diameter of 0.84 ft, the minimum required fabric strength is 22 lbf/in. Since pilot parachutes often encounter very harsh deployment conditions, they are typically over designed to accommodate unforeseen excess loading. This is possible because their small size results in adding very little to the overall system weight. Thus, the same material used for the main canopy was chosen for the pilot parachute canopy as well.

Using the maximum load, only two lines per panel on the pilot parachute (eight lines total) and the same design factor of 2.2, the minimum required strength for the suspension lines is 85.8 lbf. While very small braided nylon cord is available with just slightly higher breaking strengths, it is very difficult to work with. Thus, the more manufacture friendly MIL-C-7515, Type XI, braided nylon cord with a breaking strength of 300 lbf was chosen. This also provided for additional safety margins for the pilot parachute.

In the case of the pilot parachute, the margins of safety were calculated to be 3.2 and 2.5 for the canopy cloth and suspension lines, respectively. The weight of the pilot parachute was estimated at approximately 0.1 lbm. Construction details of the pilot parachute can be found on draft drawings included in Appendix A.

Other System Components

The main parachute is packed into a two-leaf bag that allows high pack densities to be achieved. Details of the bag construction can be found on draft drawings included in Appendix A. The bag is laced together as shown in Figure 2. The lacing is cut sequentially during deployment to allow the suspension lines and canopy to exit the bag, but force it to do so in an orderly fashion.

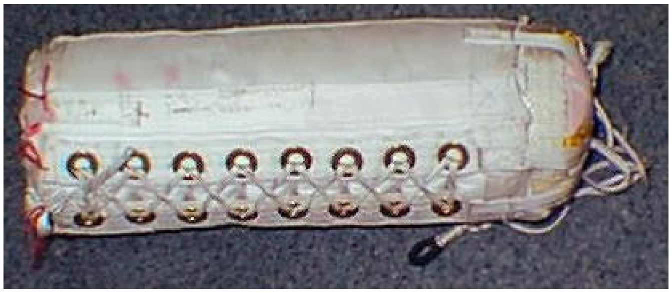


Figure 2. Main and Pilot Parachutes Assembled

The pilot parachute is packed in a "pancake" configuration as shown in Figure 3. (Drawings for the pilot parachute bag were never developed.) The pilot parachute pack is then restrained to the aft end of the main parachute pack by means of restraint loops and a retaining tie as seen in Figure 2. The retaining tie is cut when the tail-cone is ejected from the aft end, allowing the pilot parachute bag to be pulled free from the main parachute pack.

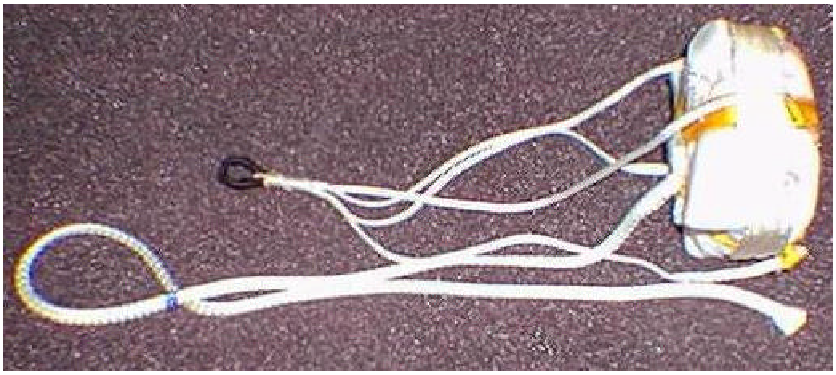


Figure 3. Pilot Parachute Packed in its Bag

The pilot parachute is connected to the main parachute bag handles via a 10-ft-long towline. This minimizes the wake effects of the penetrator forebody on the performance of the pilot parachute. The towline is made from MIL-C-7515, Type IV, 1000 lb-brkg-str braided nylon cord. This selection of material yields a margin of safety of 0.46 based upon the initial estimate of 312 lbf as the maximum developed pilot parachute load.

The confluence of the main parachute suspension lines forms a loop that allows it to be connected to a bridle placed around the TM package. This bridle is manufactured from Kevlar webbing to very close tolerances. This assures that it fits around the TM package and that the assembly fits into the tube that houses the TM package and parachute system, but does not allow the TM package to slip out of the bridle during the extreme accelerations experienced upon deployment. The construction details of the bridle can be found on draft drawings of the bridle included in Appendix A. The bridle can be seen in

Figure 4 installed around a dummy TM package (no TM antenna is in place on the top of the dummy TM package).

Figure 4. Dummy Telemetry Package Installed in its Bridle (no TM antenna present)

No formal packing manual was developed for the parachute system. A draft of a packing checklist was developed and is included in Appendix B. The procedure for attaching the parachute system to the TM package and installing it into the housing tube was documented in draft form and is included in Appendix B.

TRAJECTORY ANALYSIS/EVENT TIMING

The intended sequence of events for function of the WBS parachute system is as follows. Upon sensing the preset initiation altitude, the proximity sensor, initiates the firing of explosive bolts that retain the tail-cone. Upon explosive bolt firing, springs force the tail-cone off which, in turn, deploys the pilot parachute. The pilot parachute then inflates and subsequently deploys the main parachute. The main parachute inflates, extracts the TM package from the weapon, and begins to continuously deploy the wire from the dispenser.

With the exception of the main canopy filling and TM package/wire deployment, each of the events can be considered to occur serially, and the timing and altitude loss for each event can be estimated separately. Timing for some of the events can be estimated using simple calculations. Estimating the timing of events for the main parachute filling and TM package/wire deployment combined event required a complex calculation. As mentioned earlier, the inertial loads resulting from spooling wire from the wire dispenser on the penetrator contribute significantly to the force on the parachute. These inertial forces are highly dependent upon the rate at which the parachute decelerates the TM package which, in turn, is a function of how fast the parachute inflates. An existing computer code called DEPLOYS, originally written to model deployment of parachute suspension lines, was modified to model the wire deployment process. This was necessary since as originally written, the computer code modeled suspension lines being deployed from a parachute pack , whereas in the case of the WBS, the wire deploys from the forebody.

After the first few computer runs, it was realized that another modification to the computer code was required. As originally written, a filling time was entered for the parachute canopy. This is appropriate when the added mass of the air in the canopy is small or comparable as compared to the mass of the payload. In that instance, a fill time can be calculated based upon a nominal number of diameters of travel by the payload and the payload velocity. However, in the case of the WBS TM package, the required parachute diameter results in a very large included air mass in the canopy as compared to the weight of the TM package. This means the parachute decelerates drastically during the inflation process. In this instance it is more accurate to calculate the canopy filling process based upon the fraction of the nominal fill distance that the canopy has actually traveled. With this modification a more accurate calculation of the timing of events could be performed.

Tail-Cone Ejection/Pilot Parachute Deployment

An estimate of the tail-cone ejection velocity was made based upon the stored energy in the springs and the mass to be ejected. The energy stored in the springs can be found from simple spring theory as:

$$E_{spring} = \tfrac{1}{2} n_{springs} k x^2 \qquad (9)$$

where:

E_{spring} is the energy stored in the springs,
$n_{springs}$ is the number of springs,
k is the spring constant of an individual spring, and
x is the amount the springs are compressed.

Recalling the formula for the kinetic energy of an object, the velocity can be solved for in terms of the mass of the object and the kinetic energy as follows.

$$V_{tail-cone} = \sqrt{\frac{2E_{spring}}{m_{tail-cone}}} \tag{10}$$

where:

$V_{tail-cone}$ is the velocity of the tail-cone, and
$m_{tail-cone}$ is the mass of the tail-cone.

The initial values supplied for the springs were a spring constant of 38 lbf/in and 1.7 inches of compression. This results in 18.3 ft-lbf of stored energy. The initial estimate of the tail-cone mass was 6 lbm. Using this estimate of stored energy and mass, and ignoring any aerodynamic drag, when released the tail-cone should achieve a velocity of 14 ft/sec. This ejection process (just to release the compression in the springs) should occur over 0.016 sec. Subsequent explosive bolts tests indicated that the tail-cone would be ejected at ~20 fps. This increase in velocity could be a result of additional energy being imparted to the tail-cone due to the explosive bolts themselves. Since the forebody is travelling at nearly 1000 fps, it was estimated that there would be 16 ft of altitude loss during the process of ejecting the tail cone via the explosive bolts and springs.

Once the springs have released and the tail cone is free from the weapon, aerodynamic forces will take over and further accelerate the tail-cone and deploy the pilot parachute. This will all occur in the wake of the weapon. However, in absence of anything more accurate, free stream dynamic pressure will be used to estimate the timing of this event. The tail-cone has a flat adapter plate affixed to the inside at nearly the front edge. Thus, it can be estimated to have a drag area of a flat circular disk[3] with a drag coefficient of 1.17. The base of the tail-cone is 12 inches in diameter resulting in a drag area of 0.92 ft^2.

This drag area and the mass increments associated with deploying the pilot parachute were input into the DEPLOYS computer code referred to earlier. The estimate for the time to reach pilot parachute canopy stretch (the time the parachute is completely deployed and ready to start inflating) was calculated as 0.082 sec. In this time, the forebody has traveled 74 ft (71 ft of altitude loss at a flight path angle of 75°), and no wire has yet to be deployed.

Pilot Parachute Inflation/Main Parachute Deployment

As mentioned earlier, the DEPLOYS code was modified to use filling distance instead of time to more accurately model the canopy filling process for comparatively light payloads. The pilot parachute has a nominal diameter, D_o, of 1.28 ft. The filling distance for a parachute is commonly considered to be a multiple of its nominal diameter so that we can write:

$$d_{fill} = n_{fill} D_o \tag{11}$$

where:

d_{fill} is the filling distance and

n_{fill} is the filling constant.

For a cross parachute, the filling constant has been identified as 11.7[4]. Given the empirical nature of this constant, it was rounded to a factor of 12, and Equation (11) yields a filling distance of 15 ft.

The other input needed for the DEPLOYS code is the mass distribution of the parachute being deployed – in this case the main parachute. An estimate for the suspension line and canopy mass can be obtained by using the maximum specification weights for suspension line and canopy materials. For the materials mentioned earlier, the main parachute suspension line mass should be about 1.1 lbm equally distributed over the length of 13.5 ft. The canopy mass is estimated as 2.2 lbm and is assumed to be equally distributed over half of the canopy's constructed diameter of 10.8 ft.

The DEPLOYS code calculations estimate that the pilot parachute will be fully inflated in 0.018 seconds and will have deployed the main parachute to canopy stretch in 0.091 seconds. In this time the forebody has traveled 82 ft and experiences 80 ft of altitude loss (for a 75° flight path angle). The only resistive forces on the suspension lines are due to the inertial loads of the TM package. Since it has a mass of only 10 lbm, it will most likely move some during the process of deploying the main parachute. Thus, another calculation was made using a 10-lbm forebody. The forebody travel distance was then compared to the original calculation for the penetrator to determine how much the TM package traveled with respect to the penetrator forebody and hence how much wire was dispensed. The results were that the TM package had moved about 1.5 ft relative to the forebody, dispensing a like amount of wire. The TM package had also decelerated from an initial velocity of 900 fps (delivery velocity of the weapon) to 819 fps. This turns out to be a necessary input to the next phase of the calculation – main parachute inflation/TM package deceleration/wire dispensing.

Main Parachute Inflation/TM package Deceleration/Wire Dispensing

Using Equation (11), a filling constant of 12 (the main parachute is also a cross parachute), and a nominal diameter of 8.7 ft yields a fill distance of 104 ft for the main canopy. Using this as input, the special version of the DEPLOYS code was used that models the "suspension lines" deploying from the forebody, rather than the more typical deployment from a parachute deployment bag. Thus, the wire deploying from the dispenser could be modeled. The wire design had been finalized by this time and the actual density of 3.8 lbm/1000 ft was used for the calculation.

The forebody was calculated to hit the ground 0.61 seconds after the beginning of this phase of the calculations. The initial altitude utilized for the entire suite of calculations was 700 ft AGL. At the time of impact, the velocity of the parachute/TM package combination was 50 fps, whereas that of the forebody was 902 fps. This means the wire would be moving relative to the ground at 50 fps and spooling from the dispenser at 852 fps at the time of impact. The tension in the wire is at a maximum just below the TM package, occurs at the time of impact, and was calculated to be 83 lbf. The canopy of the main parachute was calculated to not have completely filled by the time of impact, having only achieved 80% of its full open drag area.

Full Trajectory Summary and Parametric Variations

The travel distance of both the forebody and the TM package, along with the amount of line deployed and the velocity of the wire with respect to the ground, are shown in Figure 5. The entire trajectory can be found in tabular form in Appendix C. These are the nominal values.

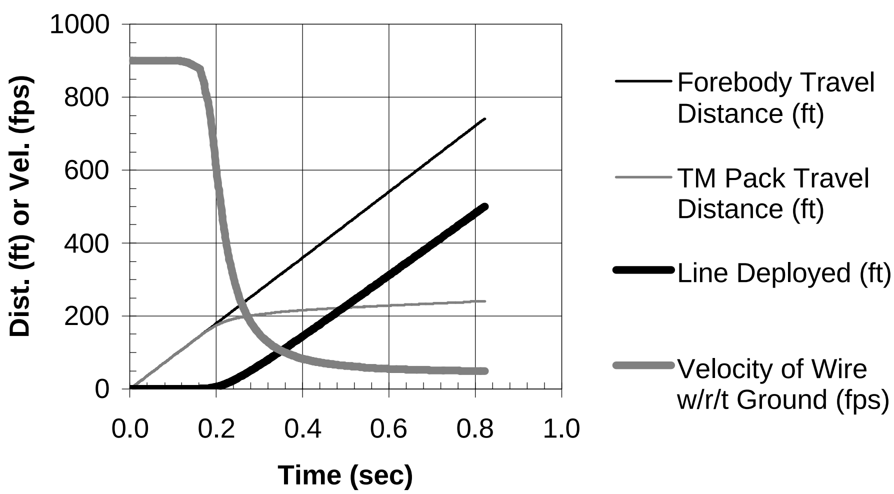


Figure 5. Weapon Borne Sensor Trajectory Parameters

Given the high velocity of the weapon, small variations in timing could result in significant variations in amount of wire deployed before impact. Variations in parachute inflation parameters could also impact the amount of time the TM package was clear of the tail section and available for acquisition of signal. Initial estimates indicated that the available acquisition time for the nominal trajectory would already be marginal. An attempt was made to bound the problem by looking at two different off-nominal cases -- the "Slow" and "Fast" deployment cases. In the "Slow" case, the variations in parameters are considered that would produce smaller amounts of line deployed and shorter amounts of time for the TM package to be clear of the tail section. In the "Fast" case, parameter variations were considered that would produce larger amounts of line deployed and longer available times for TM acquisition before impact.

The personnel developing the proximity sensor estimated its accuracy to be ±10% about the nominal trigger altitude of 700 ft AGL. Thus, in the "Slow" bounding case, an initiation altitude of 630 ft was considered, since that would produce smaller amounts of wire being dispensed and shorter acquisition times for the TM signal. Conversely, 770 ft was used for the "Fast" case. The delivery velocity can be a function of weapon release altitude and target altitude. The customer supplied the nominal value of 900 fps and the bounds of ±100 fps.

The tail cone mass and the energy in the ejection springs determine the tail cone ejection velocity. The system-integrating contractor, Applied Research Associates (ARA), estimated the nominal tail cone weight to be 6 lbm, with a +2/-1 lbm variation as reasonable bounds. A variation in the spring constant of ±15% was assumed. Using these values, the nominal ejection time of the tail cone was calculated, as shown previously, to be 0.016 seconds. Using the bounding values of tail cone mass and spring constant, the bounding values of 0.020 and 0.013 seconds were calculated for the tail cone ejection time. The corresponding ejection velocities were 11 and 16 fps.

Variations in tail cone drag area and the main and pilot parachute masses of ±15% were assumed. The pilot and main parachute filling constants were considered to vary by ±2 diameters about the nominal value of 12, yielding the bounding values of 14 and 10. The pilot and main parachute drag areas, main parachute mass, and the wire density and break-out force were varied by ±15%. The parametric variations used for the bounding calculations can be seen in Table 1. These bounding values were used in calculations by the DEPLOYS code to bound the timing and dispensed wire amounts. The elapsed time, altitude loss, and amount of wire deployed for various events is shown in Table 2 for the "Slow", Nominal, and "Fast" deployments. In addition, the velocity of the wire with respect to the ground at the time of forebody impact and the maximum acceleration of the TM package are shown.

Table 1. Parametric Variations Considered in Input Parameters for Trajectory Calculations

	Ejection Altitude, AGL	Vehicle Velocity	Tail Cone Mass	Energy in Springs	Resulting Ejection Time (Calculated)	Resulting Ejection Velocity (Calculated)	Tail Cone Drag Area	Pilot Chute Mass	Pilot Chute Filling Distance, # of Diameters (distance)	Pilot Chute Drag Area	Main Parachute Mass	Main Chute Filling Distance, # of Diameters (distance)	Wire Density	Main Chute Drag Area	Wire Breakout Force
	(ft)	(fps)	(lbm)	(ft-lbf)	(sec)	(fps)	(ft^2)	(lbm)	(-, ft)	(ft^2)	(lbm)	(-, ft)	(lbm/kft)	(ft^2)	(lbf)
Variation considered	10%	100	+2/-1	15%	-	-	15%	15%	2, -	15%	15%	2	15%	15%	15%
"Slow"	630	1000	8	15.6	0.020	11	0.78	0.25	14 (18)	0.78	3.8	14 (122)	4.4	41	3.5
Nominal	700	900	6	18.3	0.02	14	0.90	0.22	12 (15)	0.92	3.3	12 (104)	3.8	48	3
"Fast"	770	800	5	21	0.01	16.5	1.06	0.18	10 (13)	1.06	2.8	10 (87)	3.2	55	2.6

Table 2. Variations in Trajectory Parameters from Input Variable Parametric Study

	Elapsed Time			Altitude Loss			Wire Deployed		
Time Period	"Slow"	Nominal	"Fast"	"Slow"	Nominal	"Fast"	"Slow"	Nominal	"Fast"
Tail Can Ejection to End of Spring Stroke	0.020	0.016	0.013	20	14	11	-	-	-
Pilot Chute Deployed to Canopy Stretch	0.090	0.082	0.081	87	71	63	-	-	-
Pilot Chute Fill	0.019	0.018	0.017	18	16	13	-	-	-
Main Canopy Deployed to Canopy Stretch	0.078	0.076	0.078	72	64	58	1	1	1
TM Package @ 110% of Terminal Velocity	0.36	0.44	0.53	352	385	408	279	323	359
TM-Out to Impact	0.45	0.61	0.80						
Release to Impact	0.66	0.8	0.99	630	700	770	356	465	571

****

	"Slow"	Nominal	"Fast"
Velocity of Wire w/r to Ground at Impact (fps)	68	50	37
Maximum Acceleration on TM Pack (g's)	320	328	333

The acceleration of the TM package in excess of 300 g's disturbed the personnel developing that component. Thus, another series of computer runs were made in an attempt to reduce the maximum acceleration by reducing the size of the parachute. The drag area of the main parachute was reduced to 60% of the drag area of the nominal case. This resulted in a reduction in the maximum acceleration to 277 g's, but also increased the velocity of the wire at the time of impact to 58 fps. Four options were considered at this point:

1) Leave the system design as originally proposed and expect the TM system to withstand the short-lived high-acceleration pulse,

2) Reduce the main parachute size at the expense of greatly increased wire velocity,

3) Reef the main parachute momentarily to limit the drag area at first and thereby reduce the acceleration loads on the TM system, and

4) Ballast the TM package to reduce peak accelerations.

Option 4 was dismissed since the entire system was already exceeding the allowable weight. Option 3 was discounted since very short reefing cutter delay times would be needed (which typically have large variations associated with them) that would lead to large variations in amount of wire dispensed and TM acquisition time. Since the original acceleration pulse was very narrow, the TM package would have to only survive it, not operate in it. Since the threat to wire survivability in option 2 was considered to be too great, option 1 was chosen.

Late in the program the estimate for TM package weight was greatly reduced to 6 lbm. There was concern that the lighter TM package would result in attempting to dispense more wire than the dispenser held. This didn't seem likely, since the majority of the load on the parachute is inflicted by the inertial loads of dispensing the wire. However, an additional computer run was made to verify this observation. Indeed, when using a 6-lbm TM package, 472 feet of wire was dispensed compared to the 465 feet estimated for the nominal case. Thus, no changes were made to the parachute system to accommodate the lower estimate of TM weight. (The final weight for the TM package was 6.5 lbm.)

TEST RESULTS

Two static ejection tests were made of the tail-cone and pilot parachute. In each the tail-cone adequately deployed the pilot parachute. In the first test, a knife lanyard attached to the tail-cone proved to be adequate to cut the electrical ribbon cable that connected the TM package to the proximity sensor and explosive bolts in the tail-cone. Suspicion that this knife could have shorted the electrical cable and led to failure in the first full-scale flight test resulted in a design change. In the revised design, an in-line separable connector was installed in the electrical ribbon cable to eliminate the need for a knife. A second static test, on a unit that had been subjected to a full-scale vibration fly-around test, verified that the tail-cone separation would lead to pilot parachute deployment and cable connector separation.

Two flight tests of the WBS were conducted at Eglin AFB, Florida. Unfortunately, in neither of the tests did the tail-cone deploy before impact. Thus, the parachute system was never deployed and data is not available to verify the calculations. The program was terminated after the second flight and at this time no further work is planned in this area.

CONCLUSIONS

A parachute system was designed for the Weapon Borne Sensor to deploy the telemetry (TM) package and signal wire. The major system components include a 19-inch, cross pilot parachute and bag, a 130-inch, cross main parachute and bag, and a bridle for the TM package. It is estimated that when the system is deployed at 700 ft AGL, the TM package will be extracted and free of the tail section for 0.61 seconds prior to impact and experience a maximum of 365 g's. The parachute would have extracted 465 feet of wire at the time of impact and the velocity of the wire, with respect to the ground at impact, would be 50 fps.

Unfortunately, in neither of the two flight tests that were conducted was there a successful deployment of the tail-cone. The program was terminated after the second flight test. The tail-cone initiates the deployment of the parachute system, thus no comparison of the calculated values to experimental data was possible. If the program were to be resurrected in the future, close attention should be paid to verifying the modeling of the filling process of the two parachutes, especially the main parachute.

One complete system and ten pilot parachutes (packed in their bags) remained at the termination of the program. These assets were returned to the customer upon their request.

REFERENCES

[1] Knacke, T. W., Parachute Recovery Systems Design Manual, p 5-3, NWC TP 6575, Naval Weapons Center, China Lake, CA, March1991.

[2] Knacke, T. W., p 5-54.

[3] Hoerner, S. F., Fluid Dynamic Drag, Chap. 3, Fig. 33, p 3-17, published by author, 1965.

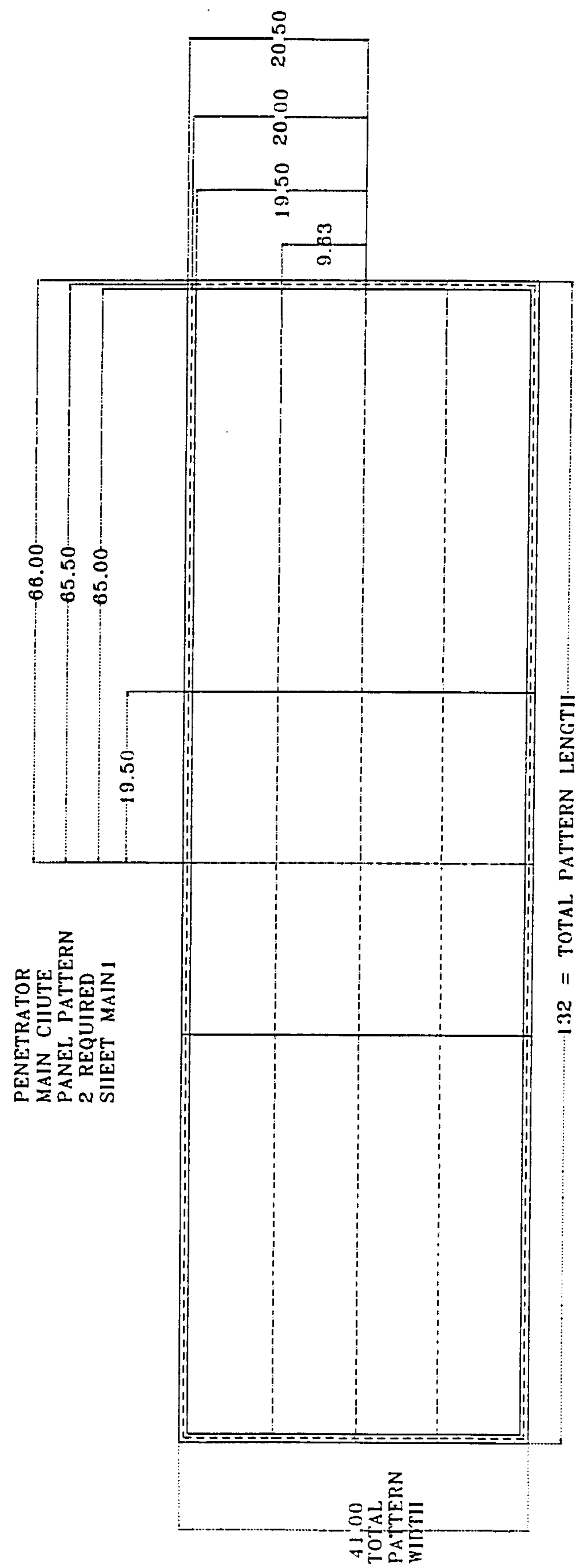
[4] Knacke, T. W., p 5-44.

APPENDICES

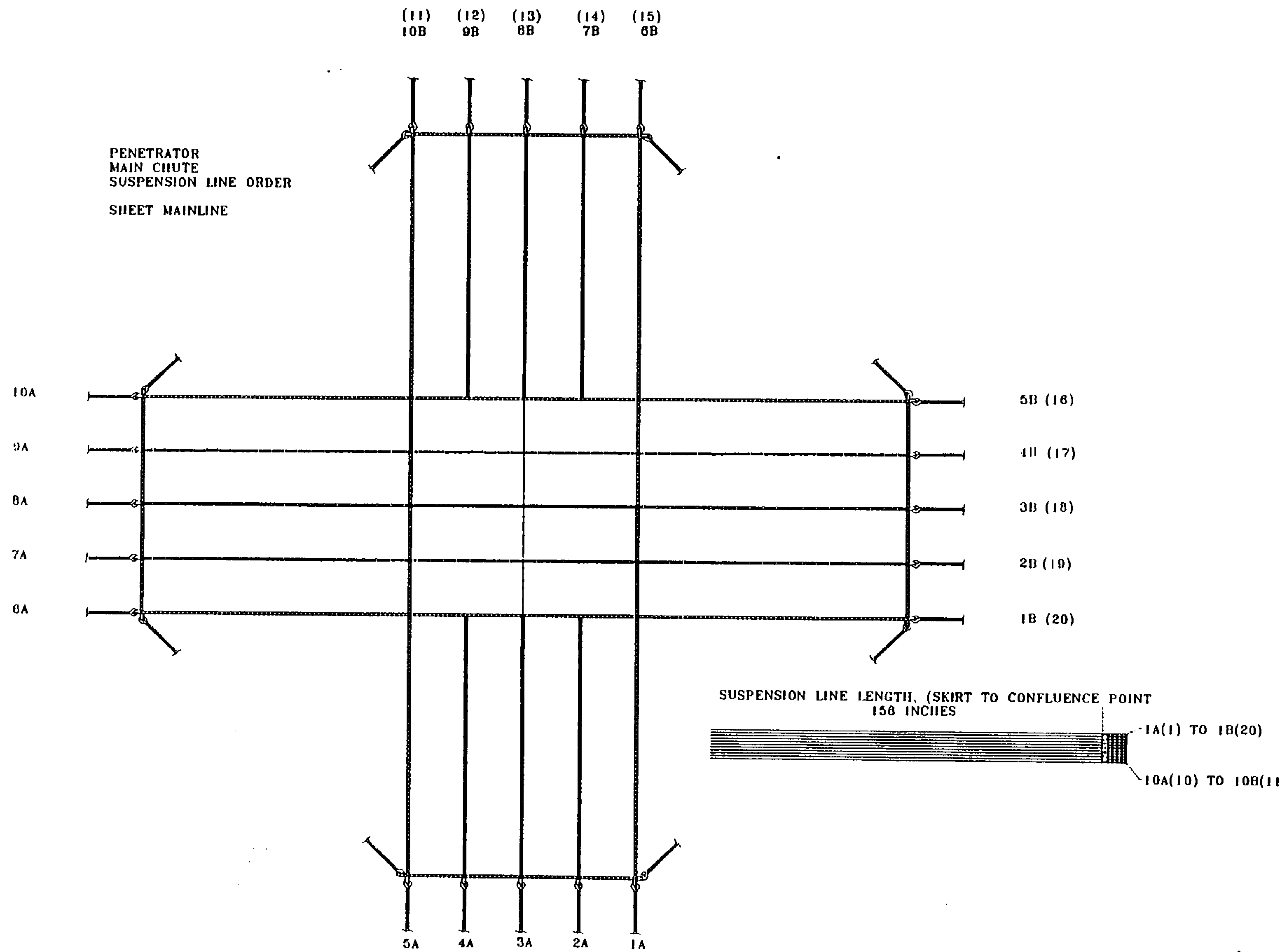
Appendix A

Draft Drawings of Parachute System Components

10.8-Ft-Dia Cross, Main Parachute Drawings

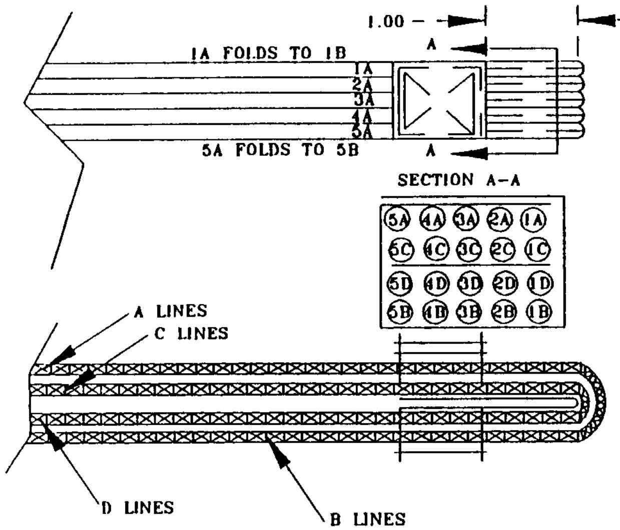


20.50
20.00
19.50
9.63
66.00
65.50
65.00
19.50
PENETRATOR
MAIN CHUTE
PANEL PATTERN
2 REQUIRED
SHEET MAIN1
132 = TOTAL PATTERN LENGTH
41.00
TOTAL
PATTERN
WIDTH

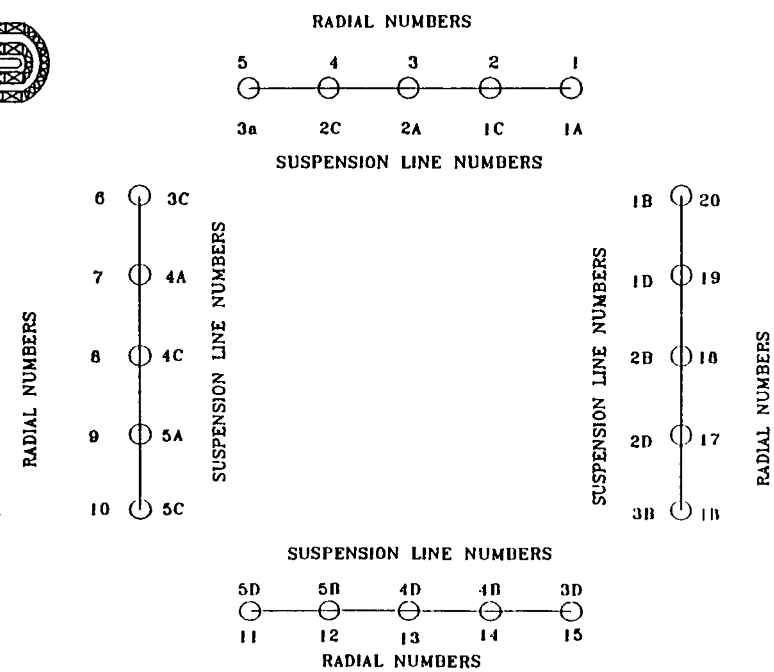


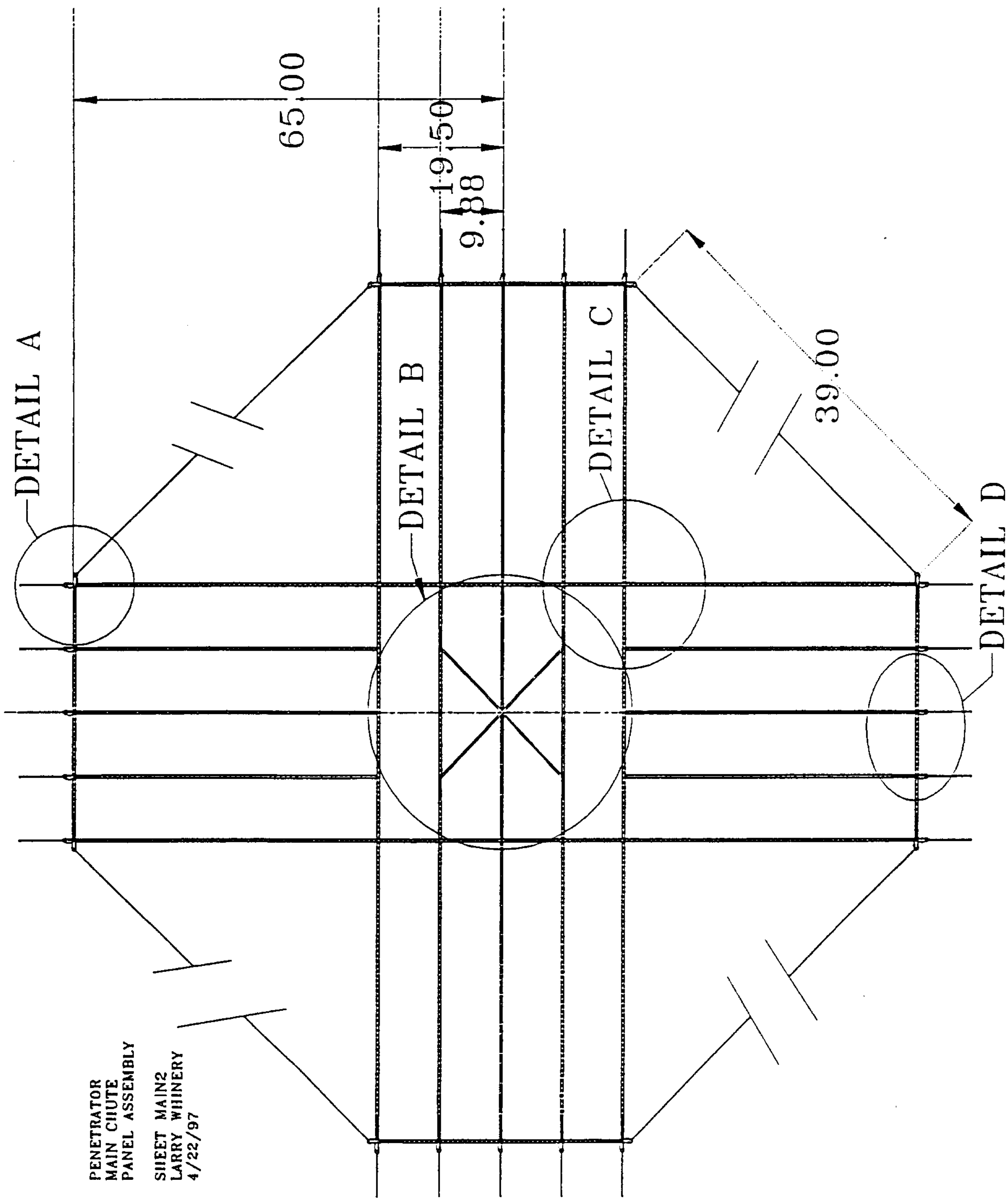
PENETRATOR
MAIN CHUTE
SUSPENSION LINE ORDER
SHEET MAINLINE
(11) 10B
(12) 9B
(13) 8B
(14) 7B
(15) 6B
10A
9A
8A
7A
6A
5B (16)
4B (17)
3B (18)
2B (19)
1B (20)
5A
4A
3A
2A
1A
SUSPENSION LINE LENGTH, (SKIRT TO CONFLUENCE POINT
156 INCHES
1A(1) TO 1B(20)
10A(10) TO 10B(11)

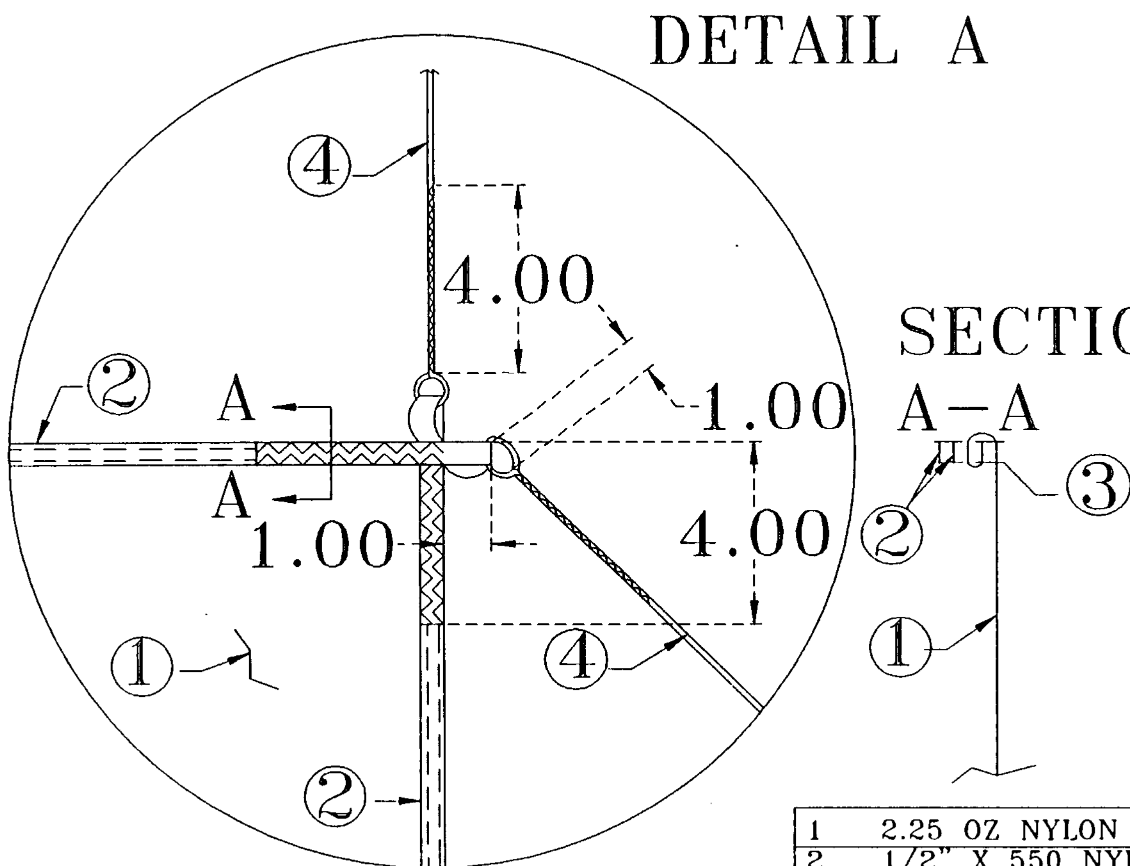
PENETRATOR LINE GROUP LOOP AND ORIENTATION



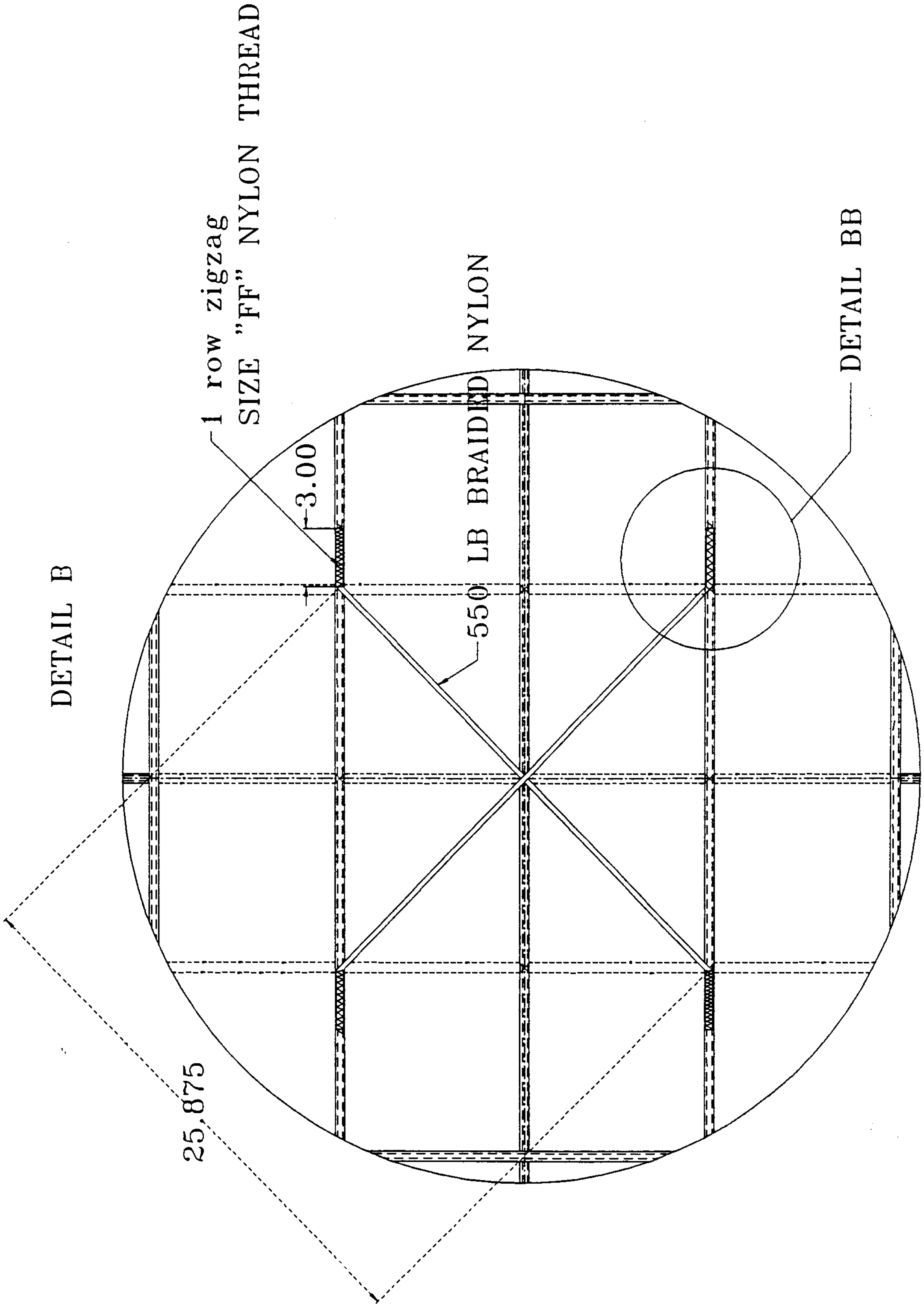
1A	TO	RADIAL 1
1C	TO	RADIAL 2
2A	TO	RADIAL 3
2C	TO	RADIAL 4
3A	TO	RADIAL 5
3C	TO	RADIAL 6
4A	TO	RADIAL 7
4C	TO	RADIAL 8
5A	TO	RADIAL 9
5C	TO	RADIAL 10
5D	TO	RADIAL 11
5B	TO	RADIAL 12
4D	TO	RADIAL 13
4B	TO	RADIAL 14
3D	TO	RADIAL 15
3B	TO	RADIAL 16
2D	TO	RADIAL 17
2B	TO	RADIAL 18
1D	TO	RADIAL 19
1B	TO	RADIAL 20

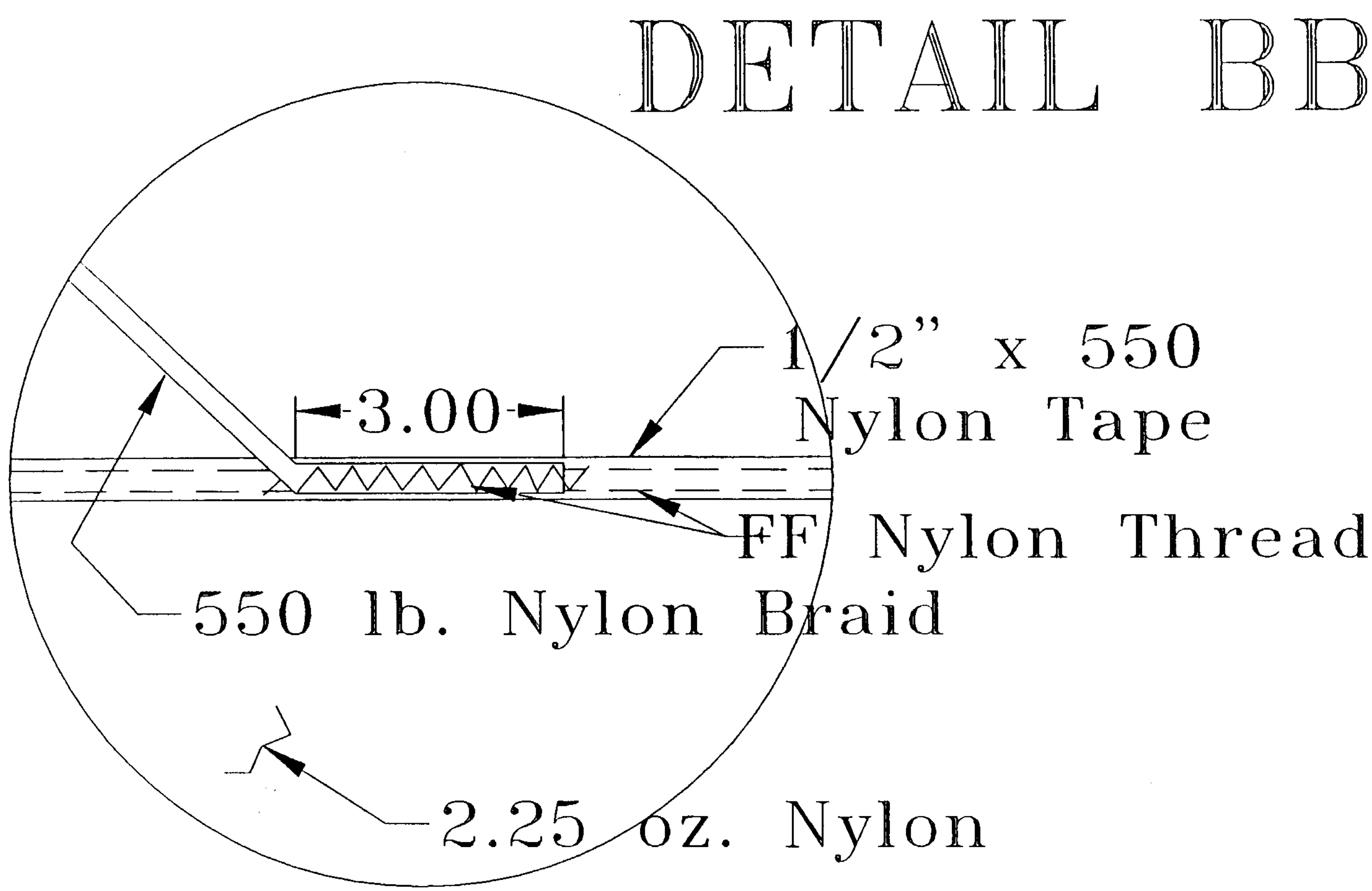



DETAIL A
DETAIL B
DETAIL C
DETAIL D
65.00
19.50
9.88
39.00
PENETRATOR
MAIN CHUTE
PANEL ASSEMBLY
SHEET MAIN2
LARRY WHINERY
4/22/97

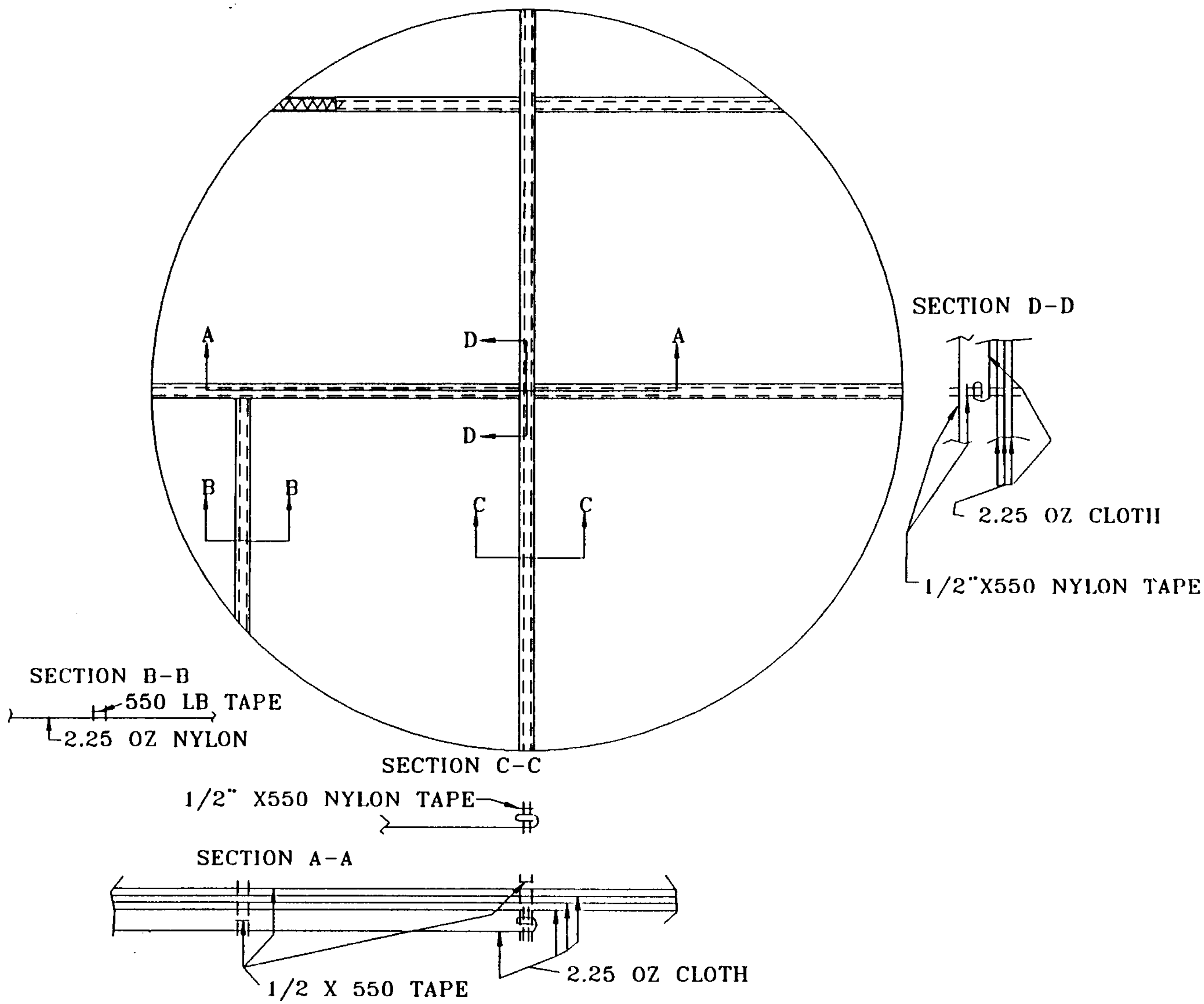


1	2.25 OZ NYLON CLOTH
2	1/2" X 550 NYLON TAPE
3	SIZE FF NYLON THREAD
4	550 LB. BRAIDED NYLON

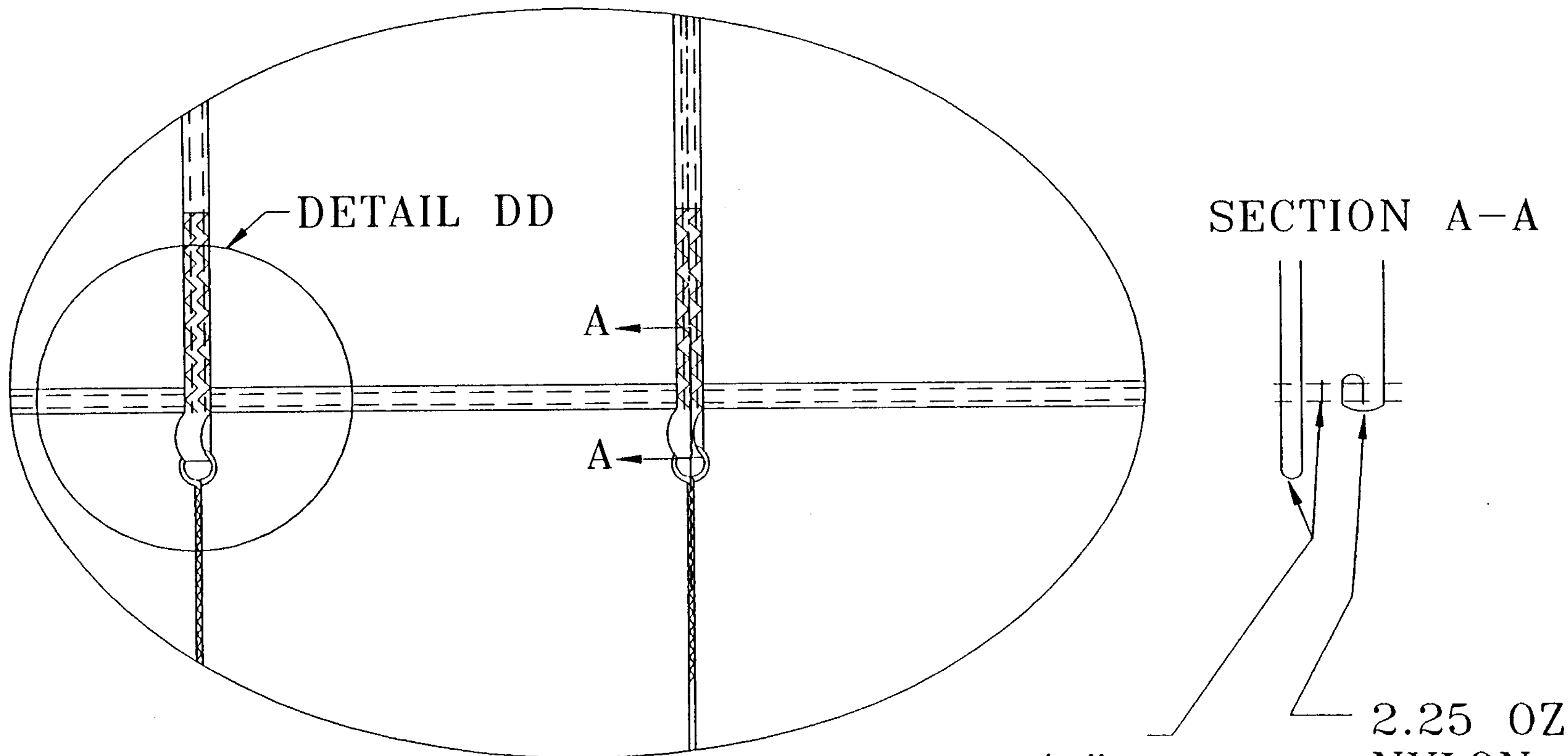

DETAIL B
1 row zigzag
SIZE "FF" NYLON THREAD
3.00
550 LB BRAIDED NYLON
DETAIL BB
25.875


DETAIL BB
1/2" x 550
Nylon Tape
-3.00-
FF Nylon Thread
550 lb. Nylon Braid
2.25 oz. Nylon

DETAIL C

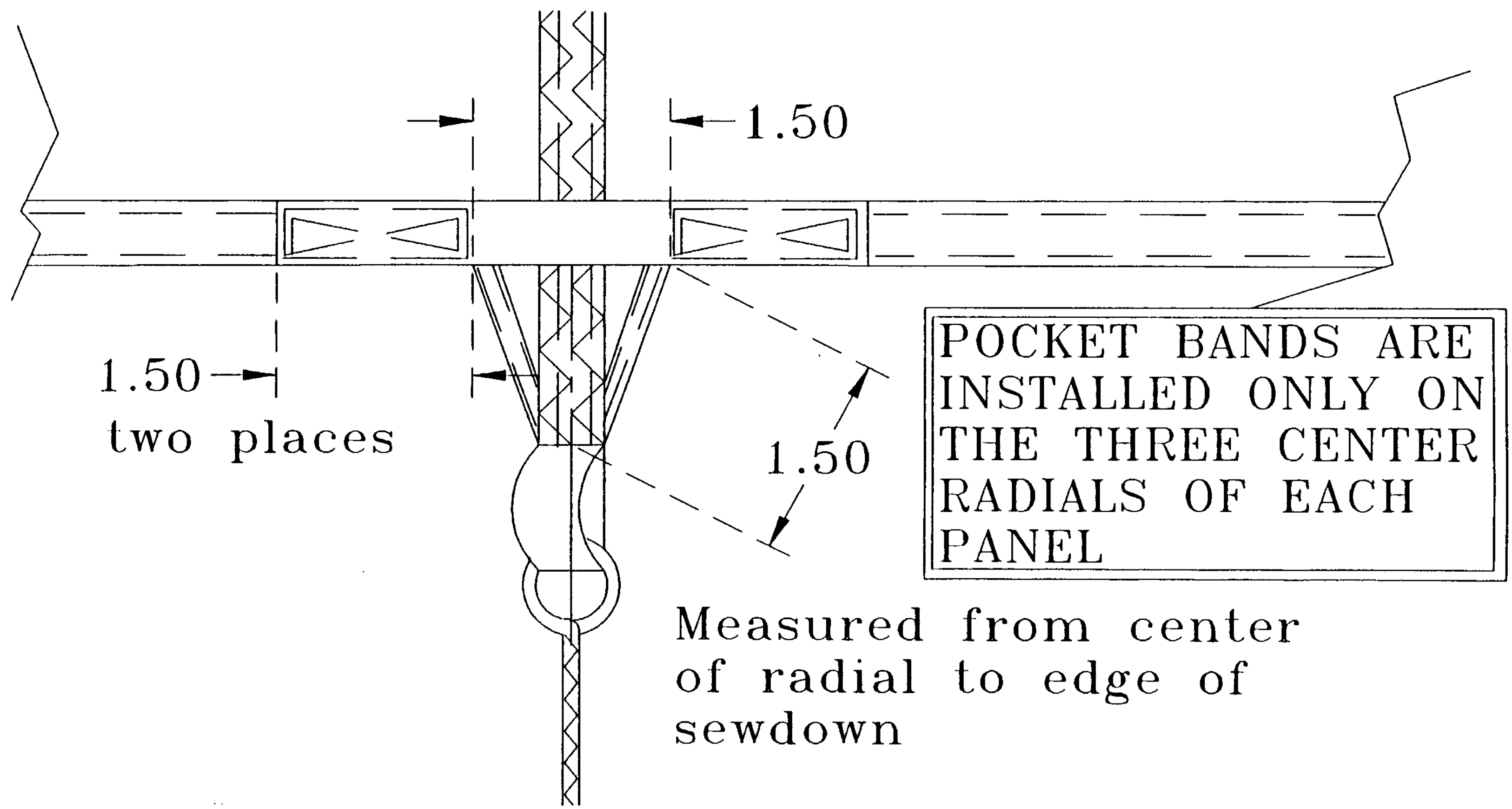

A
A
D
D
B
B
C
C
SECTION D-D
2.25 OZ CLOTH
1/2"X550 NYLON TAPE
SECTION B-B
550 LB TAPE
2.25 OZ NYLON
SECTION C-C
1/2" X550 NYLON TAPE
SECTION A-A
1/2 X 550 TAPE
2.25 OZ CLOTH

DETAIL D



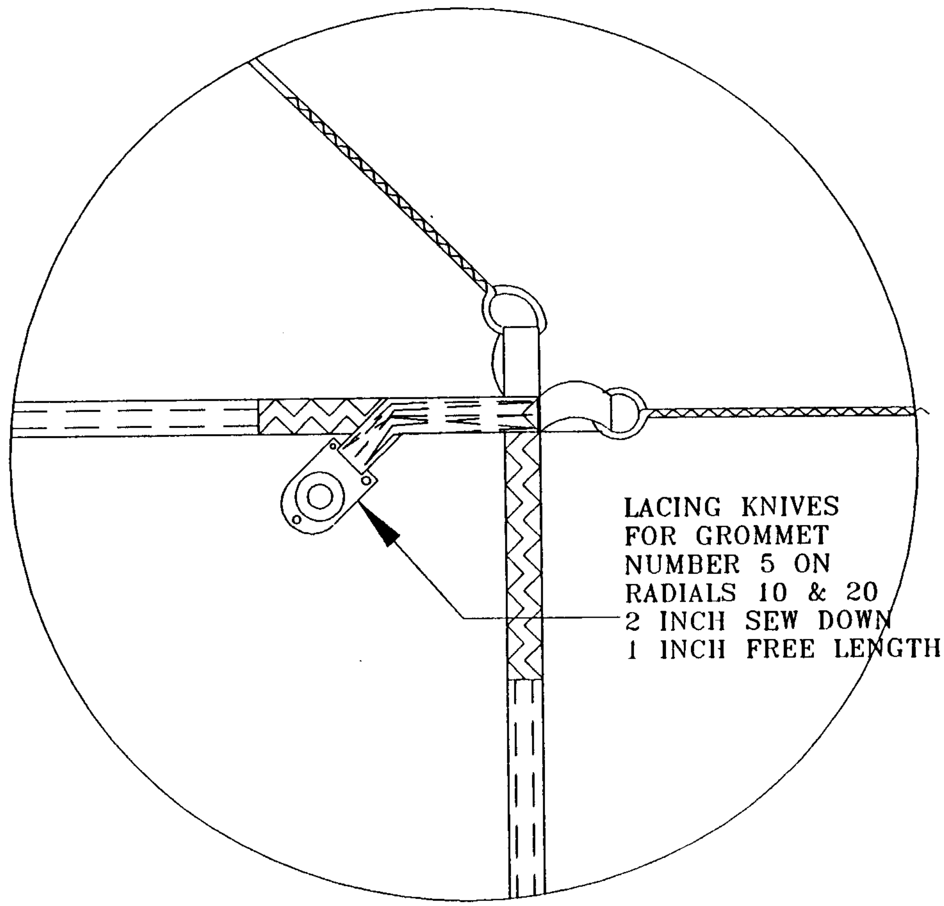
VIEW IS PRIOR TO INSTALLATION OF POCKET BANDS. SEE DETAIL DD.

DETAIL DD



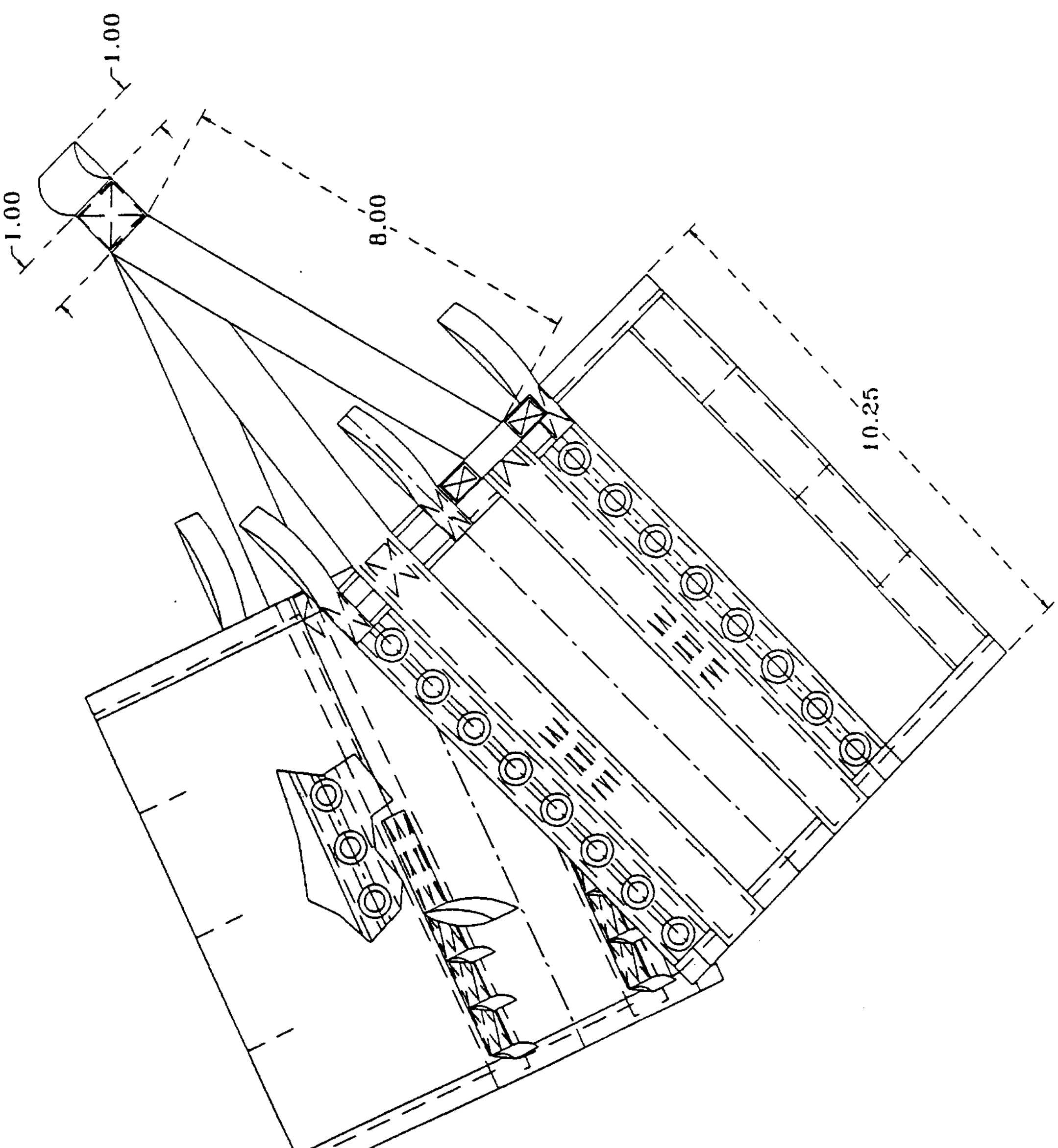
POCKET BAND INSTALLATION

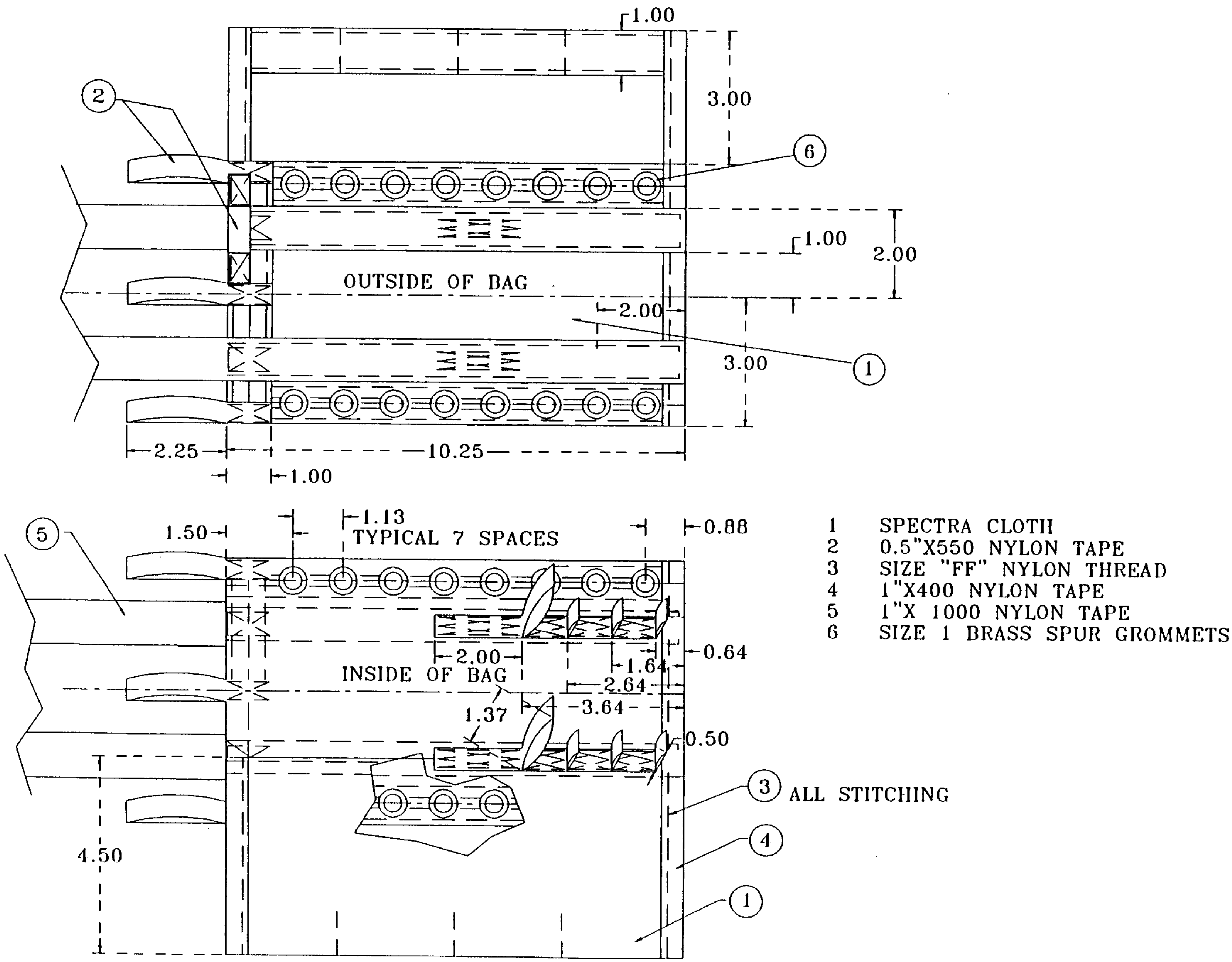
DETAIL E


LACING KNIVES
FOR GROMMET
NUMBER 5 ON
RADIALS 10 & 20
2 INCH SEW DOWN
1 INCH FREE LENGTH

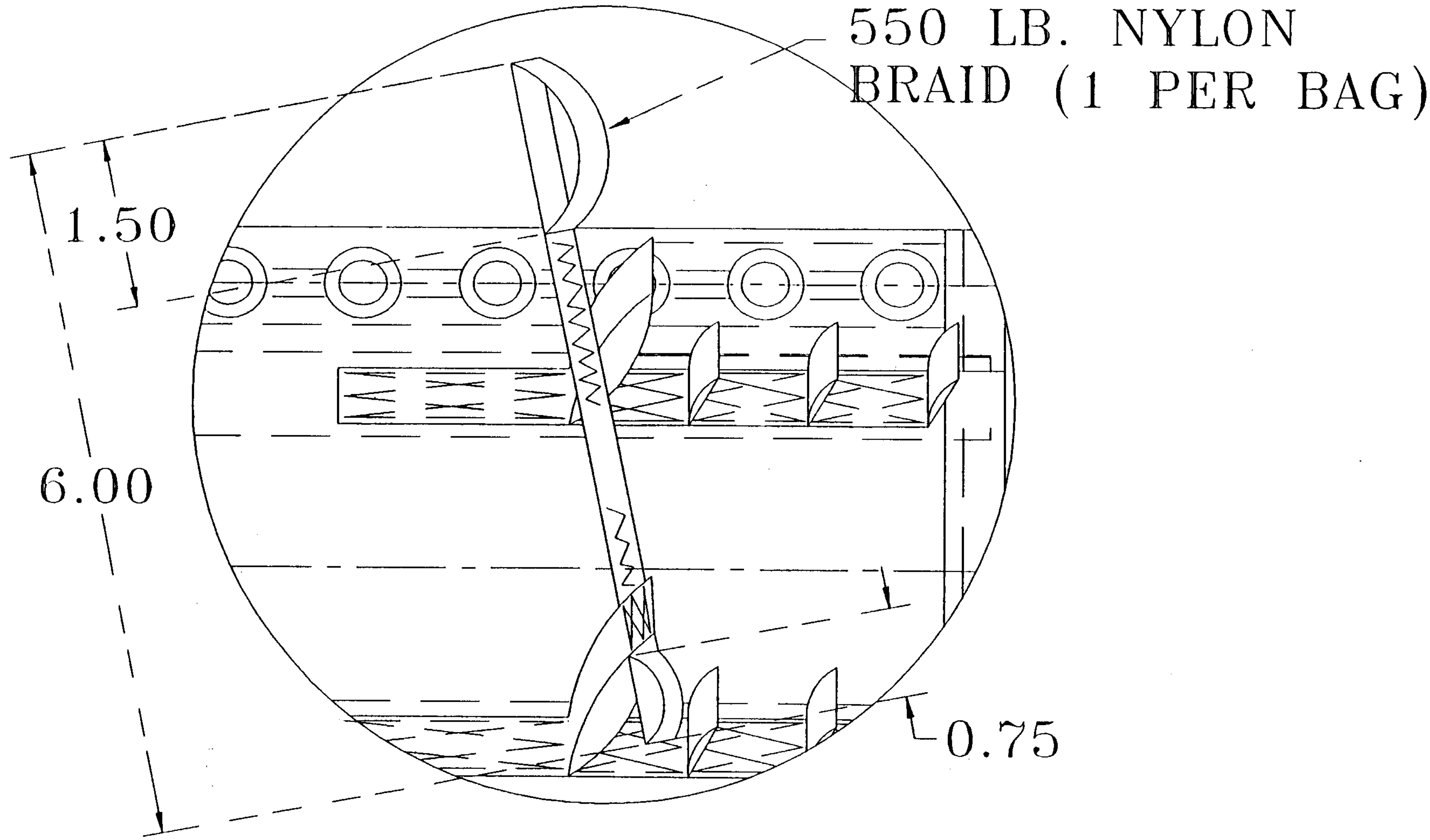
Main Parachute Bag Drawings

MAIN BAG ASSEMBLY

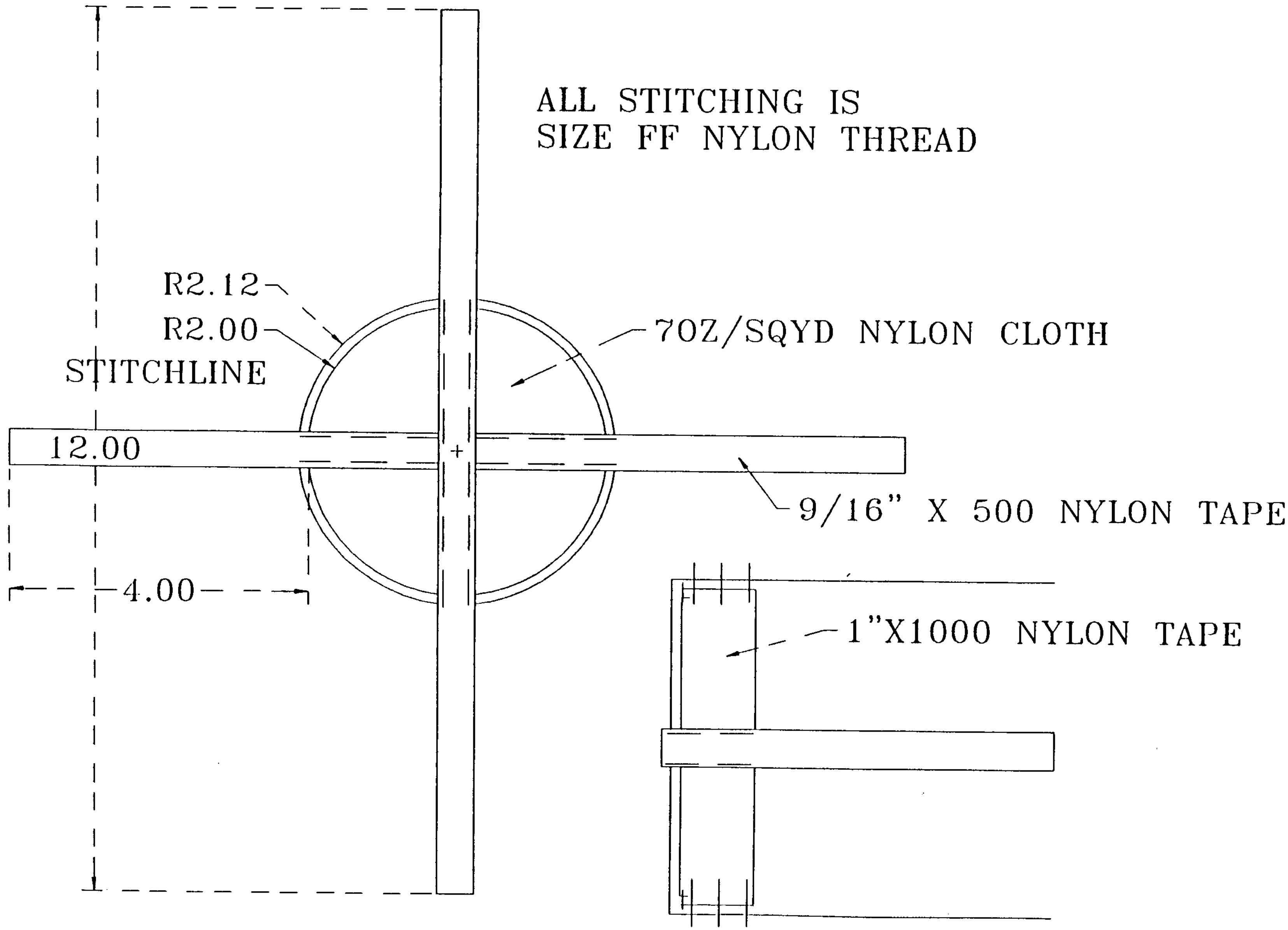


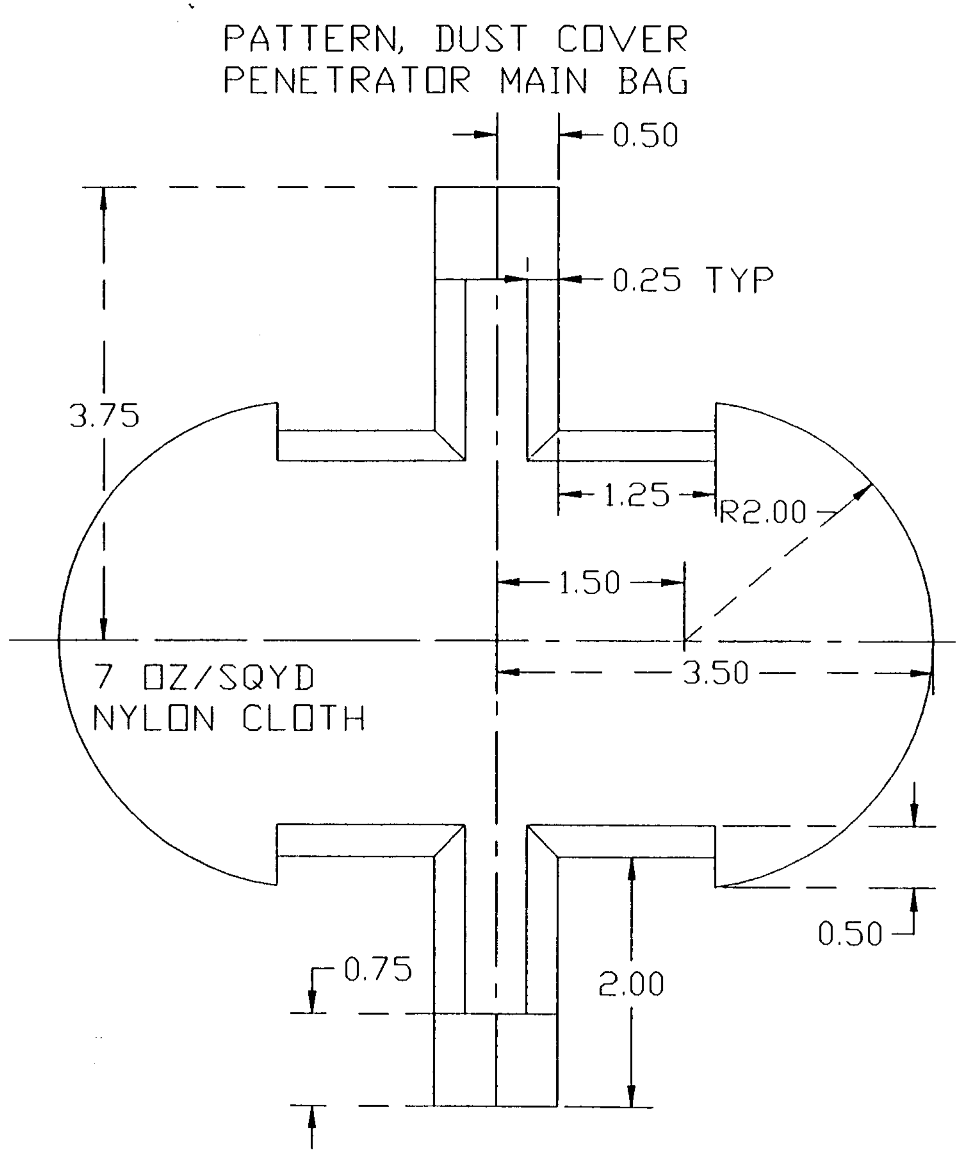

1.00
3.00
2
6
1.00
2.00
OUTSIDE OF BAG
2.00
3.00
1
2.25
10.25
1.00
5
1.50
1.13
TYPICAL 7 SPACES
0.88
INSIDE OF BAG
2.00
1.64
0.64
2.64
3.64
1.37
0.50
3 ALL STITCHING
4
4.50
1
1 SPECTRA CLOTH
2 0.5"X550 NYLON TAPE
3 SIZE "FF" NYLON THREAD
4 1"X400 NYLON TAPE
5 1"X 1000 NYLON TAPE
6 SIZE 1 BRASS SPUR GROMMETS

MAIN BAG DETAIL A

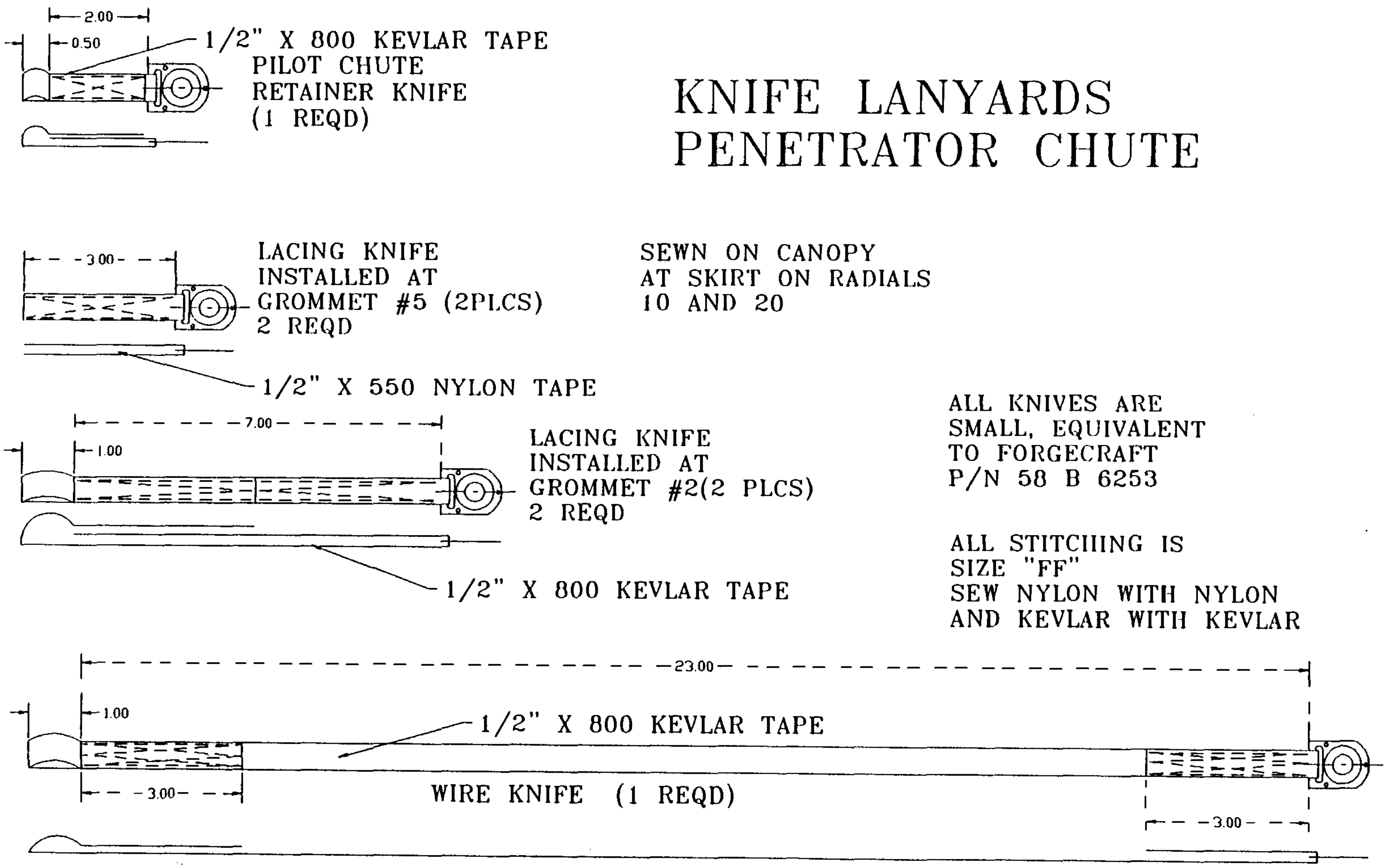


PENETRATOR MAIN BAG END CAP



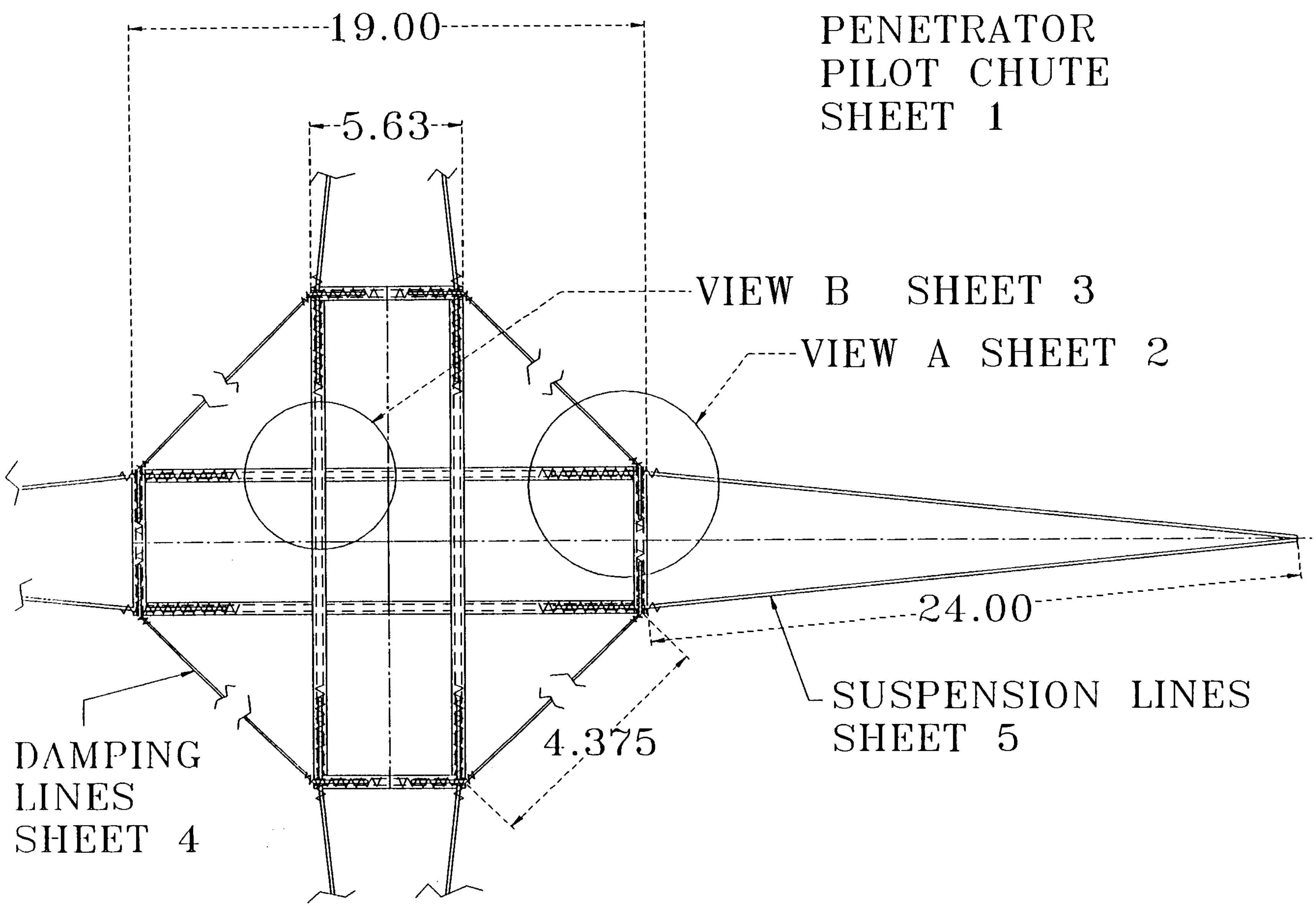

PATTERN, DUST COVER
PENETRATOR MAIN BAG
0.50
0.25 TYP
3.75
1.25
R2.00
1.50
3.50
7 OZ/SQYD
NYLON CLOTH
0.50
0.75
2.00

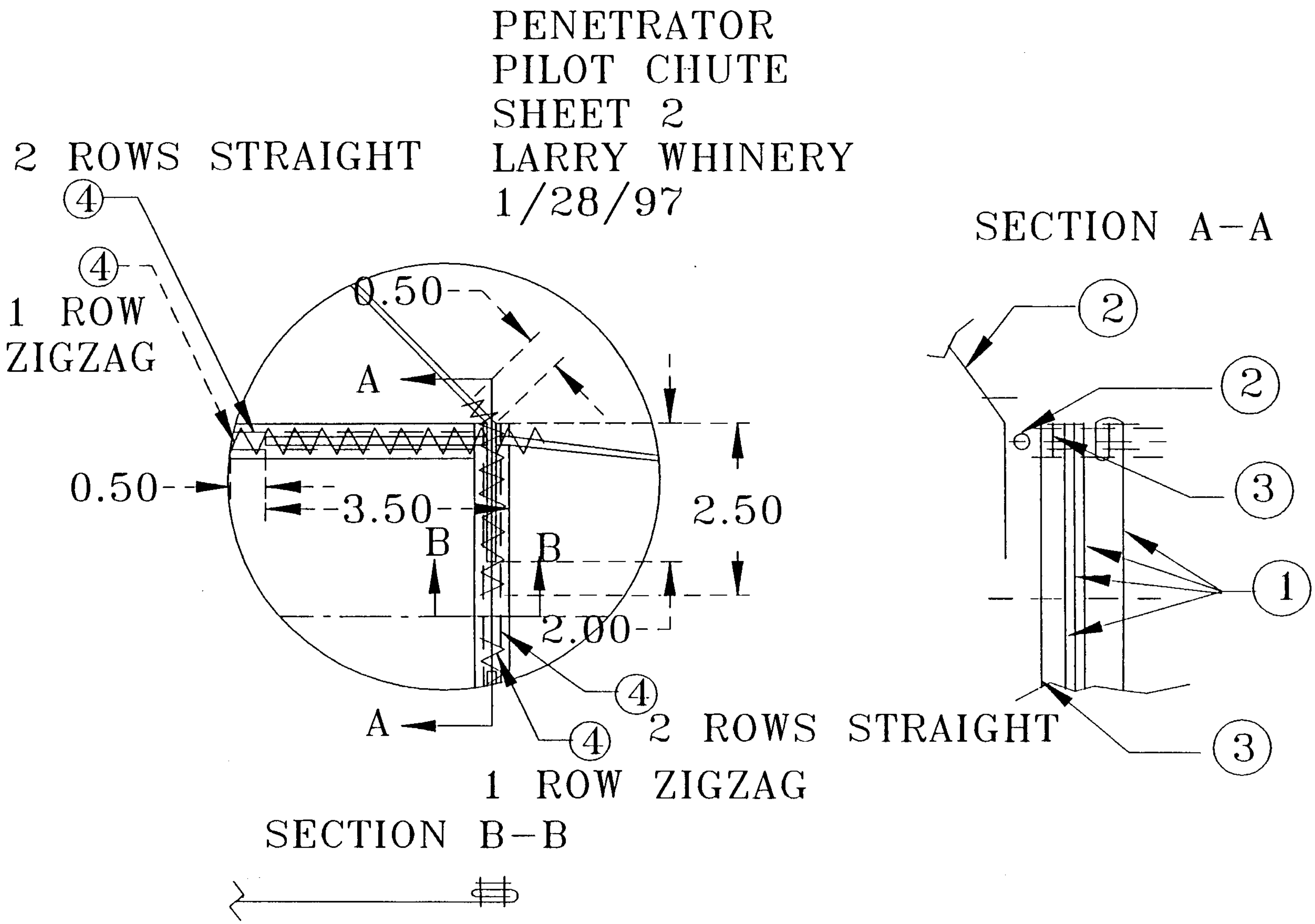
KNIFE LANYARDS PENETRATOR CHUTE



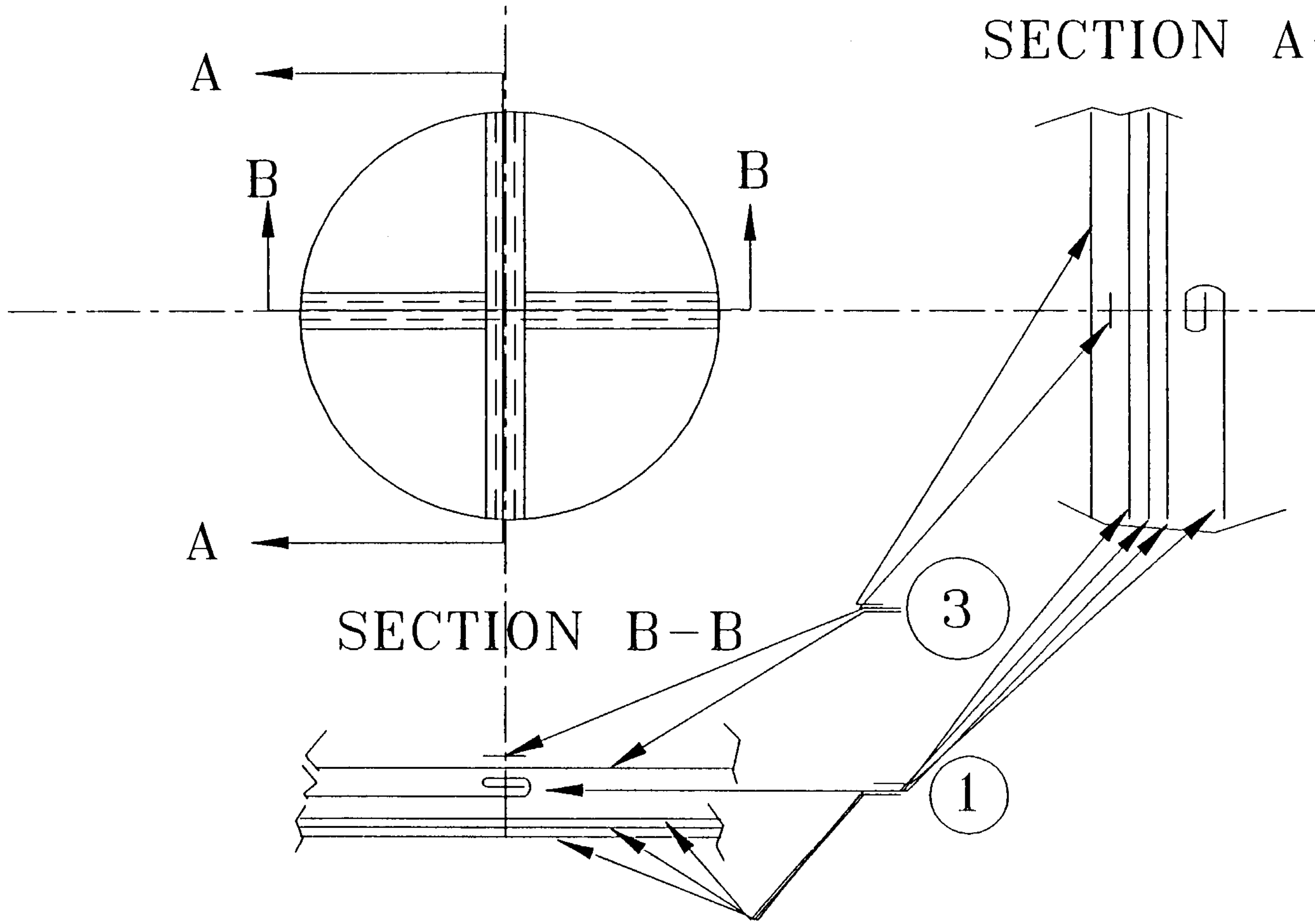
1.3-ft-dia Pilot Parachute Drawings

ITEM	SPECIFICATION	PART	DESCRIPTION
1	MIL-C-7350 TYPE I	CANOPY PANELS	CLOTH, NYLON 2.25 OZ/YD
2	MIL-C-7515 TYPE XI	SUSP.LINES, DAMP.LINES	CORD, BRAIDED, NYLON, 300 LB. BS
3	MIL-T-5038 TYPE IV	SKIRT BAND, RADIALS	TAPE, NYLON 1/2"X550 LB. BS
4	V-T-295	SEWING	THREAD, NYLON, SIZE "FF"

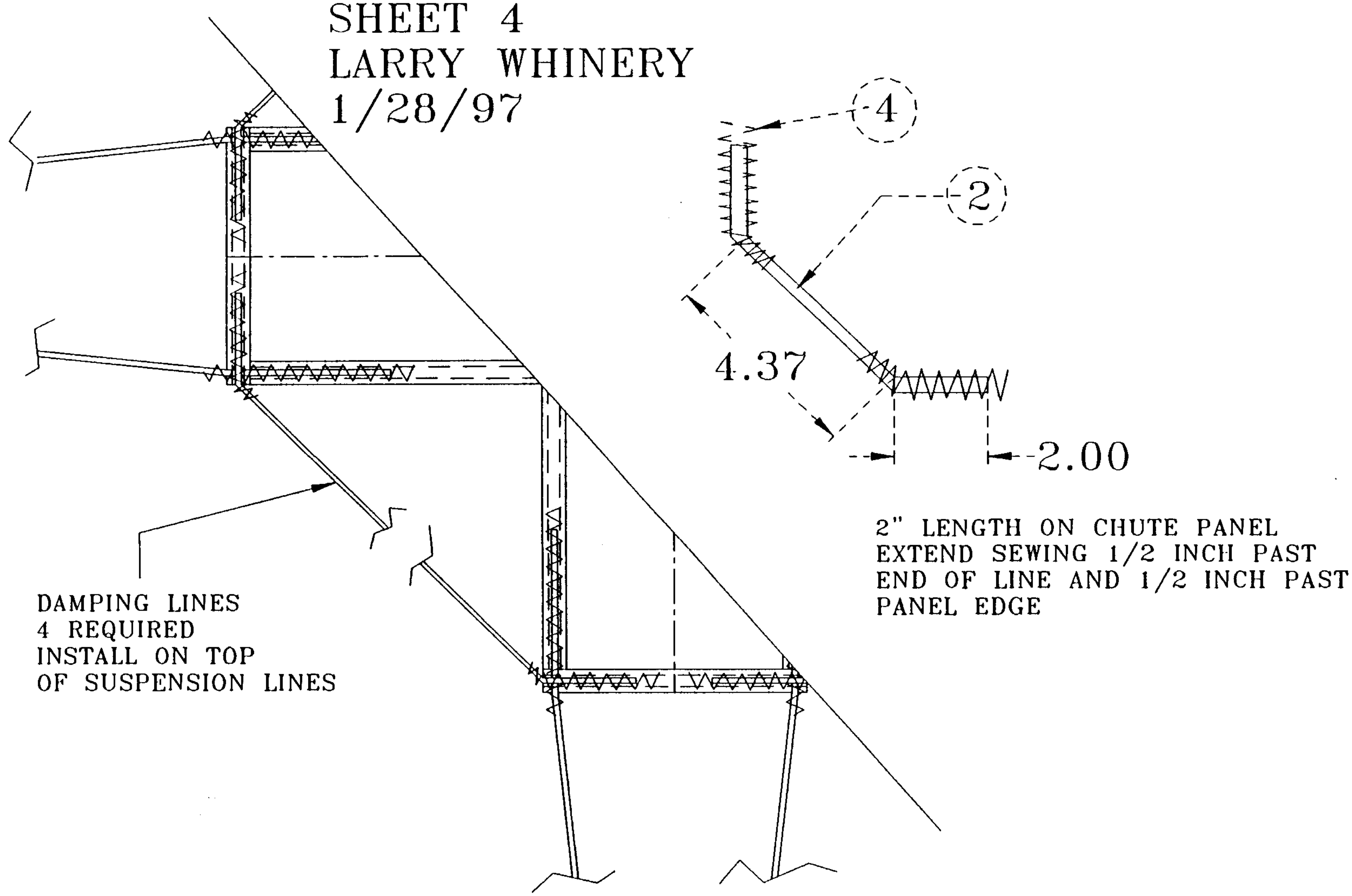

19.00
5.63
PENETRATOR
PILOT CHUTE
SHEET 1
VIEW B SHEET 3
VIEW A SHEET 2
24.00
SUSPENSION LINES
SHEET 5
4.375
DAMPING
LINES
SHEET 4


PENETRATOR
PILOT CHUTE
SHEET 2
LARRY WHINERY
1/28/97
2 ROWS STRAIGHT
4
4
1 ROW
ZIGZAG
0.50
0.50
3.50
A
B
B
A
2.50
2.00
4
4
2 ROWS STRAIGHT
1 ROW ZIGZAG
SECTION B-B
SECTION A-A
2
2
3
1
3

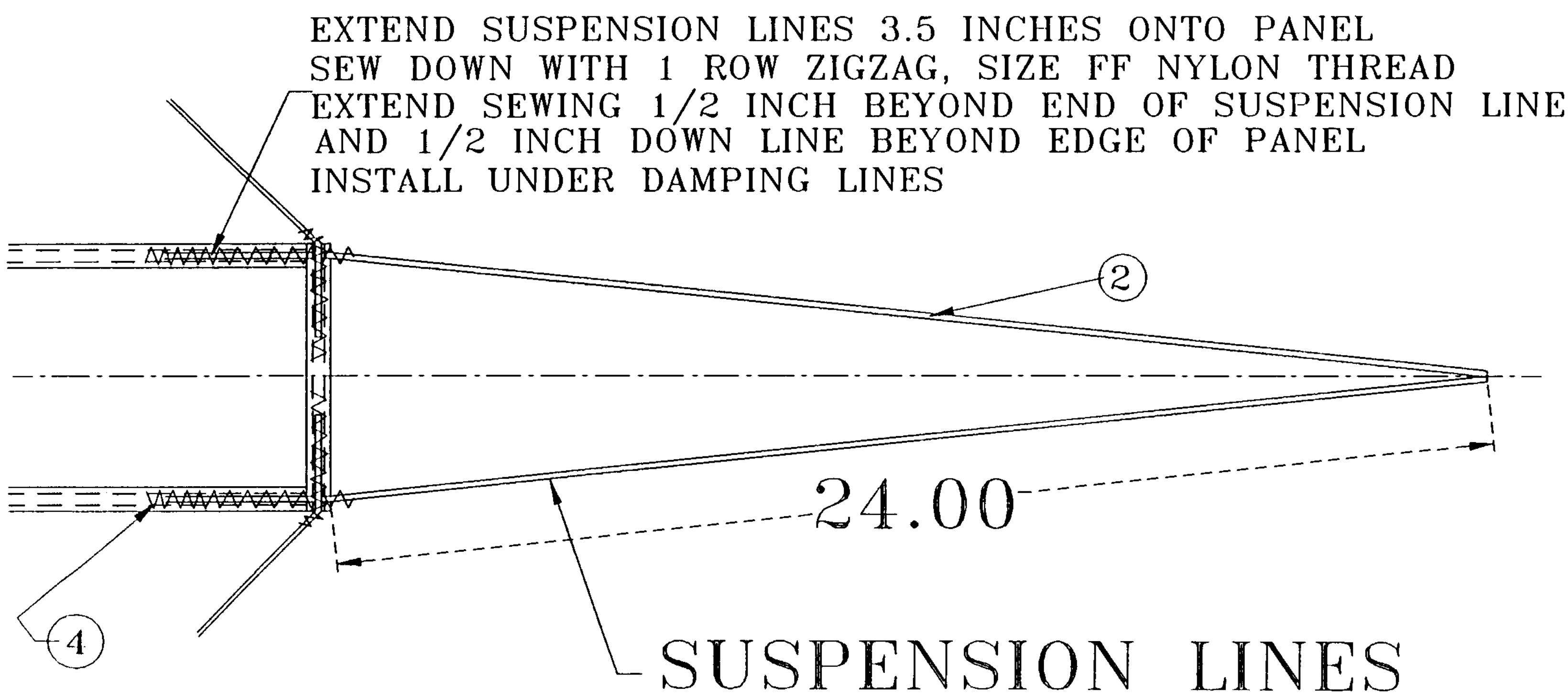
PENETRATOR PILOT CHUTE
SHEET 3



PENETRATOR PILOT CHUTE DAMPING LINES
SHEET 4
LARRY WHINERY
1/28/97

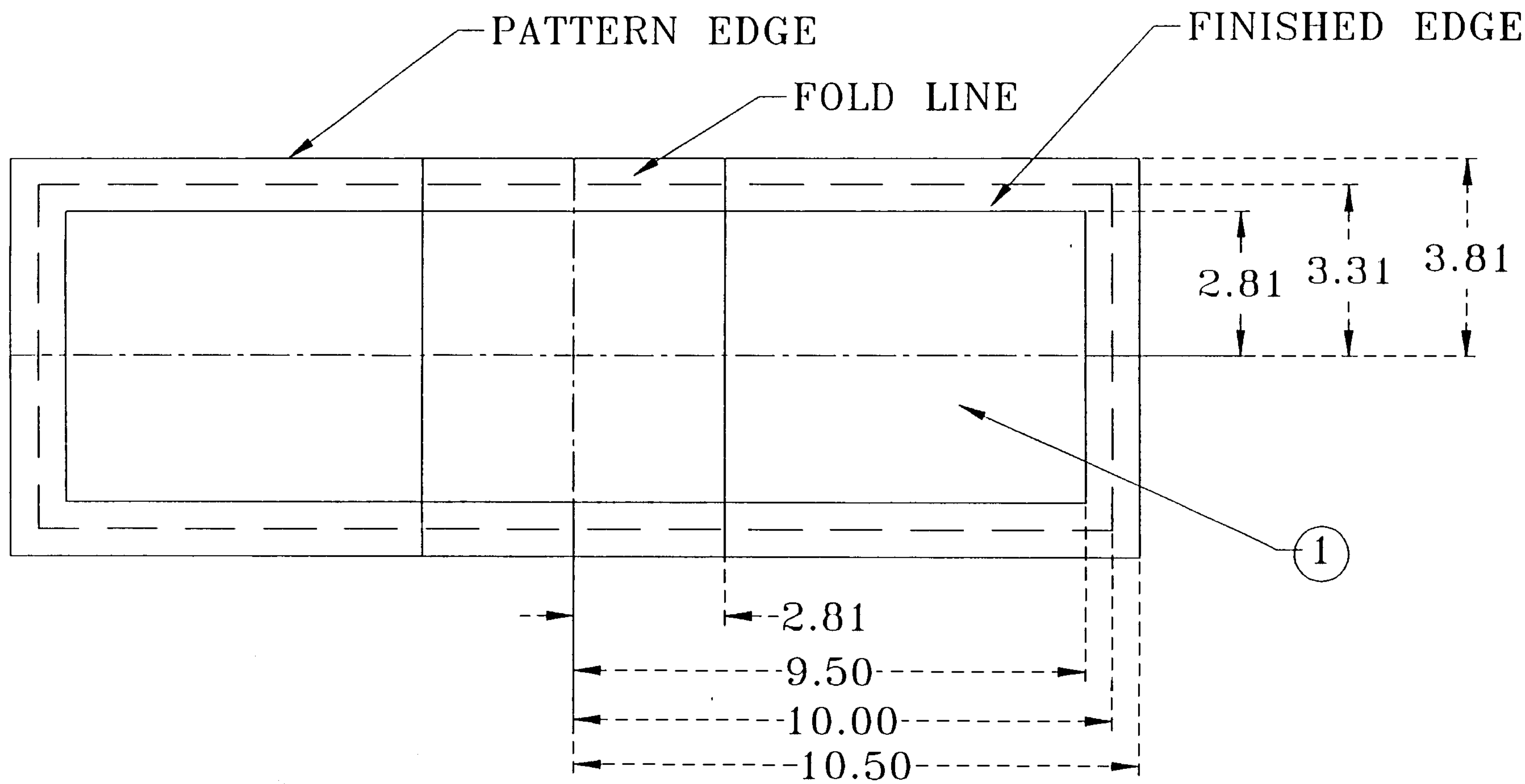


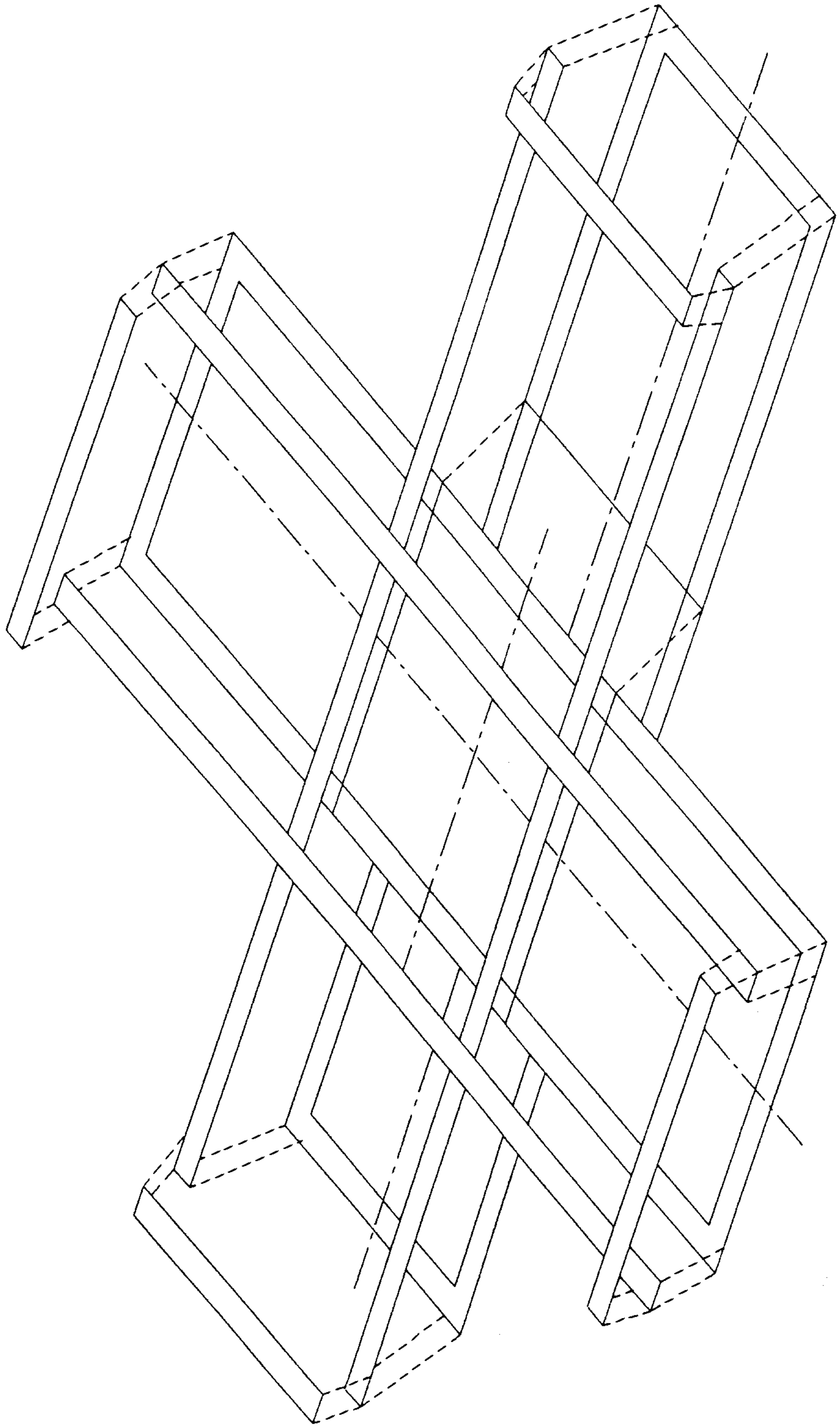
PENETRATOR PILOT CHUTE   SHEET 5
LARRY WHINERY   1/28/97



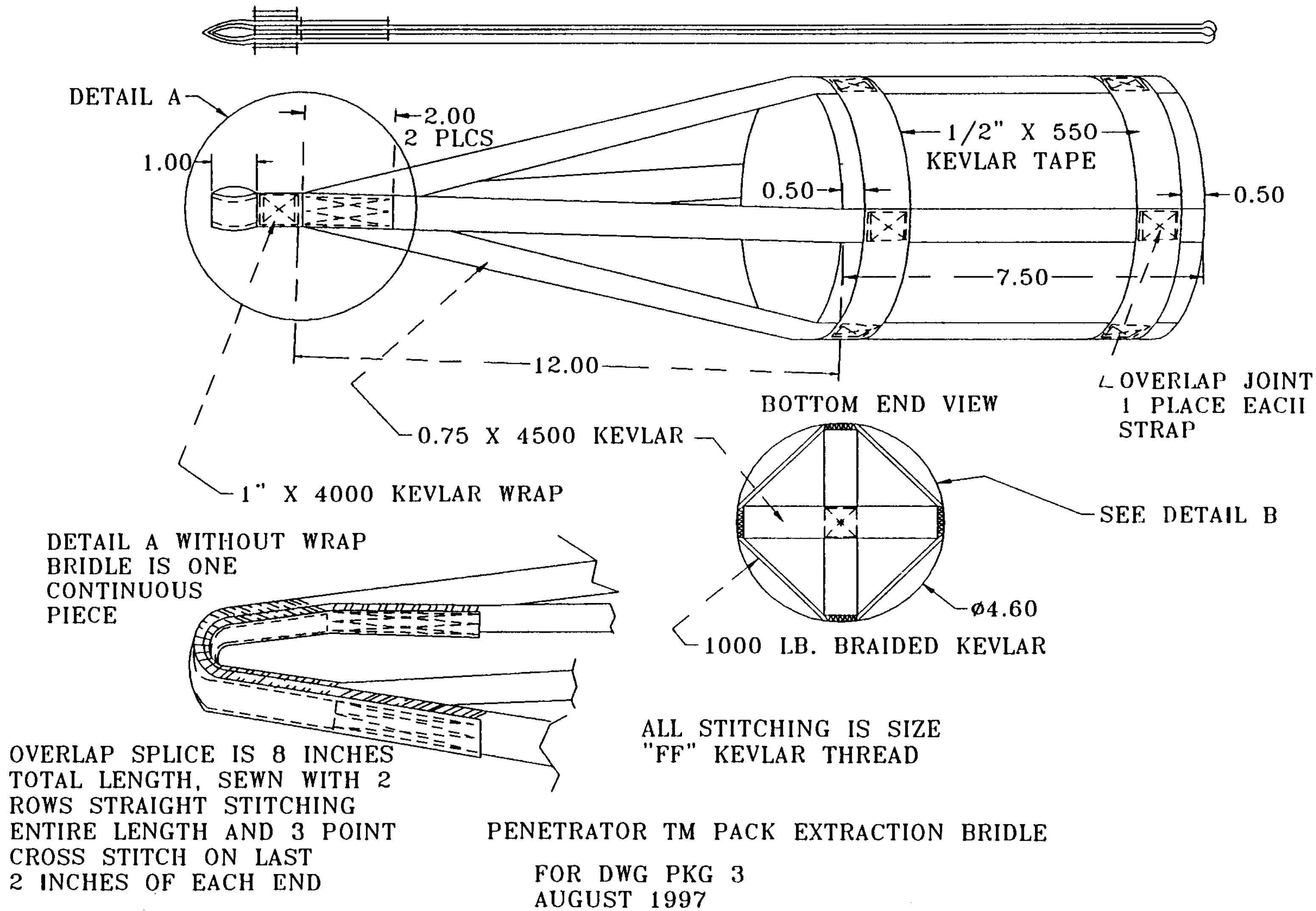
4 SETS OF SUSPENSION LINES WILL BE JOINED TOGETHER AT LOOP END BY SERVING ALL LINES TOGETHER TO FORM A 1" FLAT LOOP

PENETRATOR
PILOT CHUTE
PANEL PATTERN
SHEET 6

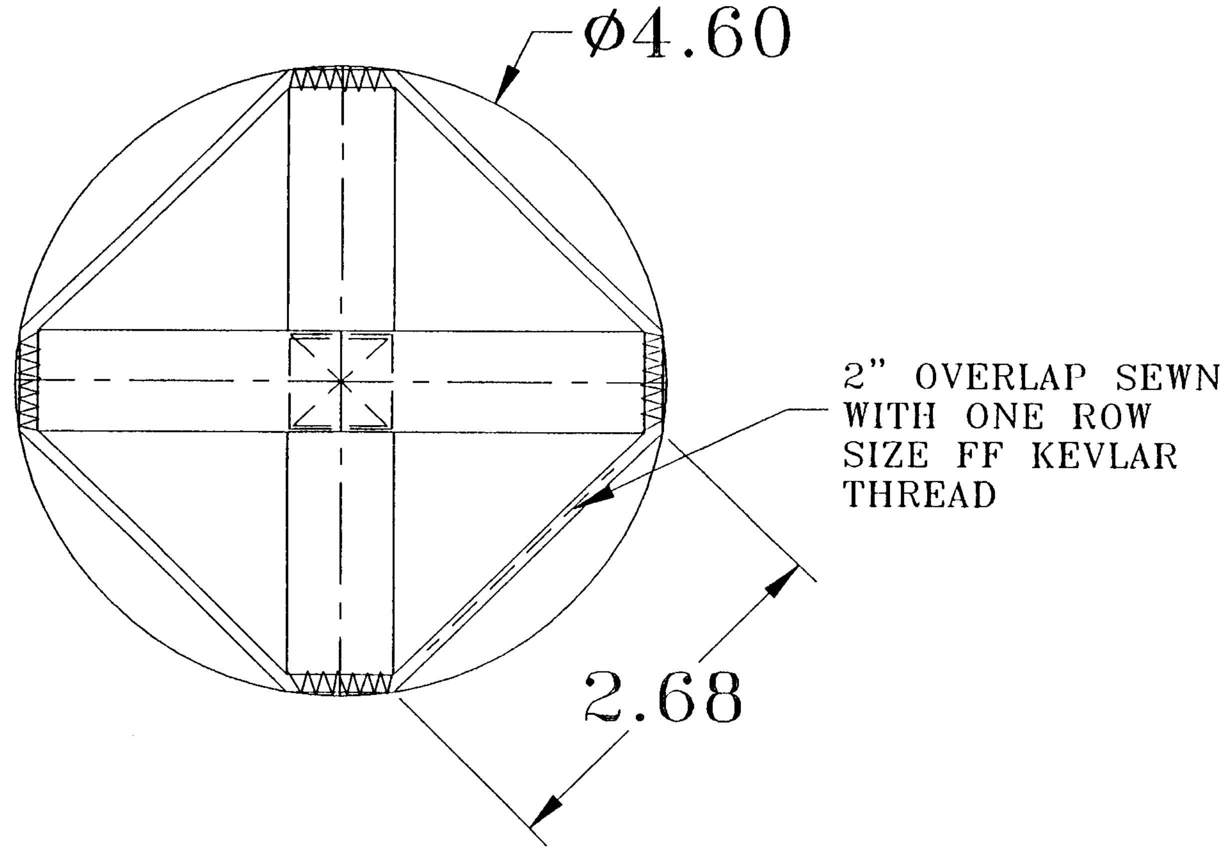




Telemetry Package Sling Drawings


DETAIL A
1.00
2.00
2 PLCS
1/2" X 550
KEVLAR TAPE
0.50
0.50
7.50
12.00
OVERLAP JOINT
1 PLACE EACH
STRAP
BOTTOM END VIEW
0.75 X 4500 KEVLAR
1" X 4000 KEVLAR WRAP
SEE DETAIL B
DETAIL A WITHOUT WRAP
BRIDLE IS ONE
CONTINUOUS
PIECE
Ø4.60
1000 LB. BRAIDED KEVLAR
ALL STITCHING IS SIZE
"FF" KEVLAR THREAD
OVERLAP SPLICE IS 8 INCHES
TOTAL LENGTH, SEWN WITH 2
ROWS STRAIGHT STITCHING
ENTIRE LENGTH AND 3 POINT
CROSS STITCH ON LAST
2 INCHES OF EACH END
PENETRATOR TM PACK EXTRACTION BRIDLE
FOR DWG PKG 3
AUGUST 1997

TM PACK EXTRACTION BRIDLE DETAIL B



Appendix B

WBS Parachute System Packing Checklist

and

Draft WBS/Telemetry Package Integration and Installation Manual

Parachute Serial Number	
Built to Drawing Package #	
Pack Number	
Date Packed	
Packed by	
Inspected by	

	Rigger	Inspector
Install packing plate to the closed end of the deployment bag using double 5 cord nylon thread, color red, through the holes provided		
Lay out canopy on table and straighten lines		
Attach vent break cord (100 lb nylon cord) around vent lines and tie with a bowline knot and an overhand knot		
Mark the vent line at 18" from the knot around vent lines		
Attach vent break cord to the loop at the closed end of deployment bag at the 18" mark and tie with a bowline knot and an overhand knot		
Install temporary lacing on the deployment bag		
Install the deployment bag into the packing fixture can		
Install temporary line ties around the lines at 12" spacing starting at the skirt. Use YELLOW 90 lb. tape ----12 ties, tied with a bow knot		
Fold the canopy to a width of approximately 8"		
Stow the canopy into the bag by accordian folding until the skirt band is below the canopy retainer loops of the bag.		
Pull the two lacing knives installed on radials #10 and #20 to the outside		
Thread the free end of the retainer loop through the canopy retainer loops, around the suspension lines and through the other loop of the retainer		
Pull a byte of suspension lines through the canopy retainer loop		
Starting with the first temporary line tie, fold the suspension lines over and tie to one of the lowest bag ties of either bag panel using Ticket # cotton cord.		
NOTE: Make the tie by passing the cord through the bag loop, completely around the byte of suspension lines, and then tying the two free ends with a surgeon's knot and an overhand knot.		
Make the second line tie in the same manner using one of the lowest bag loops of the opposite bag panel.		
Continue tying lines to the lowest available bag loops, alternating bag panels on each tie.		
After all line ties are made (12) remove all 12 temporary line ties		
Verify that all 12 temporary ties are removed		
Tack the suspension line group loop to the inside of the bag so that the end of the loop is even with the end of the bag panel using 1 turn of single size 5 nylon cord, color red, with the knot on the outside of the bag.		

Install the dust cover to the open end of the deployment bag using one turn of single size "E" nylon thread 8 places.		
Work the dust cover pocket down into the pack by pushing the suspension lines to the side.		
Install the End plate into the dust cover slot and tack to the bag panels using double size 5 nylon cord through the holes provided.		
Install the lacing knives attached to the skirt band at radials #10 and #20 to the bag over grommet #5 of each bag panel on the side opposite the gusset. Tack in place with double Size 5 nylon cord, color red, with the knot on the outside of the bag.		
Tack the knives again using single size 5 Nylon cord through the hole at the end of the knife blade. Put the knot on the outside of the bag.		
Install the lacing knives on grommet number 2 of each bag panel in the same manner as above.		
Thread the lanyard end of the lacing knives at grommet number 2 between the bag panel and the end packing plate.		
Remove the temporary lacing from the bag panels		
Lace each side of the pack using 300 lb. braided nylon. (Double laced)		
Pull the parachute down to a circumference less than 14"		
Single the lacing on both sides of the pack and tie off each end using two half hitches and an overhand knot.		
Cut out the temporary tacks on the lacing knives and the temporary tack on the suspension line group loop		
Attach the free end of the pilot chute line cord (2000 lb braided nylon) to the deployment bag bridle loop. Pass the line through the loop and secure using a Chinese Finger, 4 inches long. Place the mark of the line at the bag loop.		
Sew the Chinese finger with one row of straight stitching, size "FF" nylon thread.		
Fold the line under the pilot chute and center the pilot chute over the closed end of the main deployment bag.		
Run a length of size 5 nylon cord through 3 adjacent pilot chute retainer loops, through the pilot chute retainer knife, and through the other 3 retainer loops and tie using a square knot with overhand knot.		
Safety the retainer knife to the bag using single size "E" nylon thread, 2 places.		

WBS Parachute Installation Procedure

Figure 1 shows the TM pack with antenna and ribbon wire, the TM bridle and the main parachute pack. (See Figure 1)

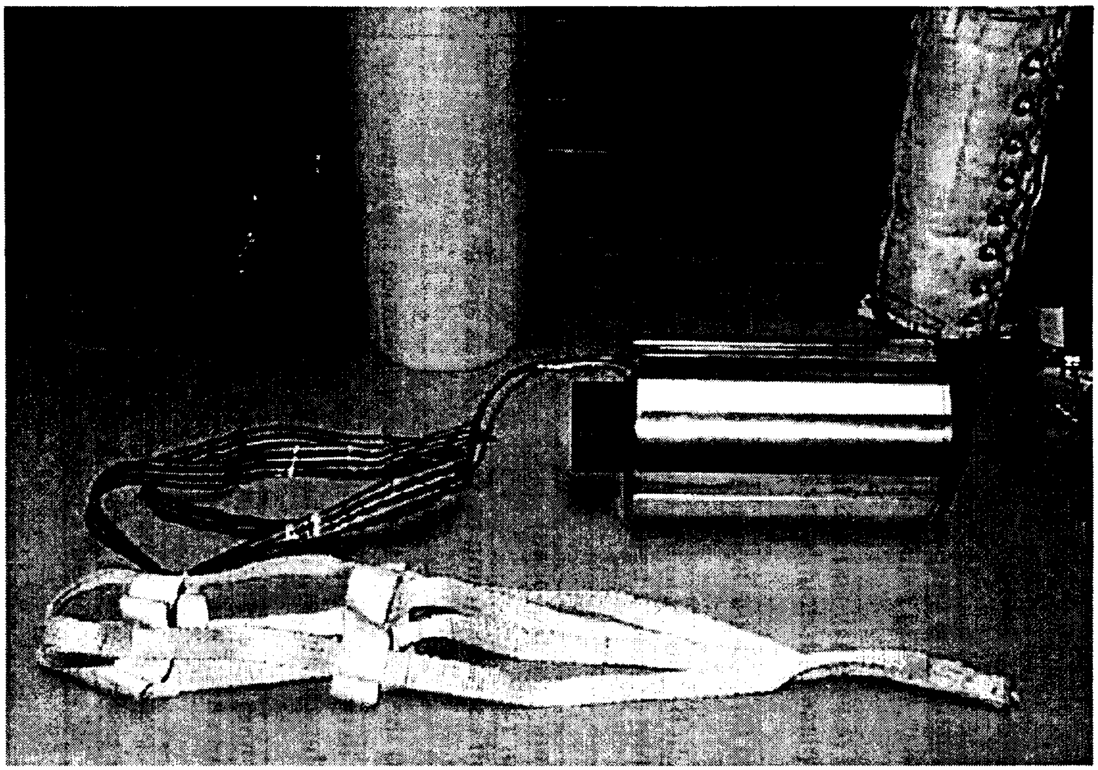


Figure 1

1. Install TM bridle around TM Pack so that the antenna of the TM pack faces the end loop of the bridle and the crossover webbing of the bridle is against the flat bottom of the TM pack.

2. Ensure that the legs of the TM Bridle fit into the slots of the TM Pack and the edges of the retention bands (2 each) lay flat with no turn backs. (See Figure 2.) Align the TM Bridle so that the outer, non-spliced leg of the bridle is at the location where the ribbon wire exits the TM pack.

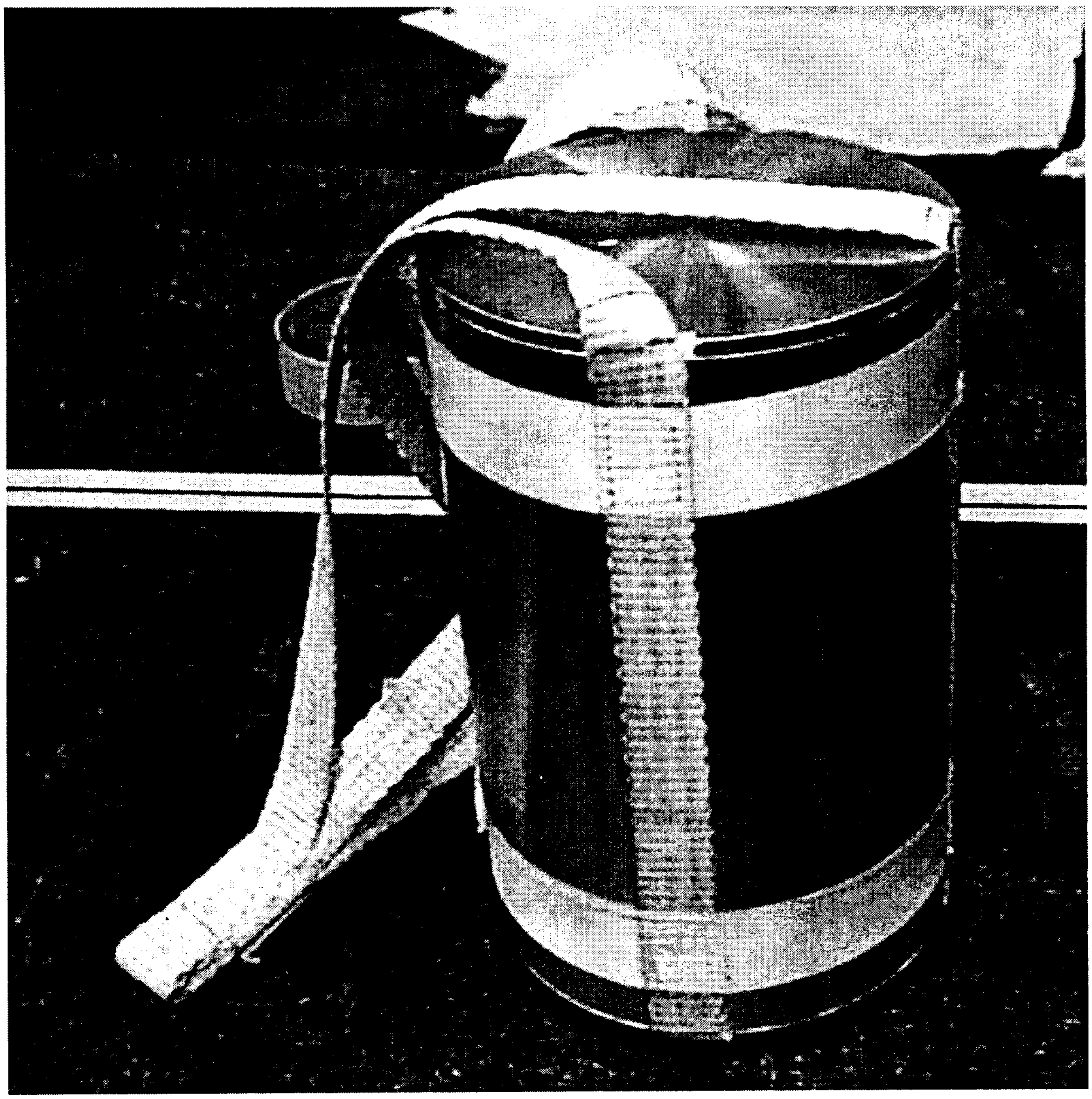


Figure 2

3. Keeping the ribbon wire straight, route the wire around to the outside of the nearest bridle leg. Hand tack the wire to the bridle leg in three places: one near the TM Pack, one in the middle of the bridle leg and one near the confluence point of the TM bridle, using one turn of waxed Size 5 nylon cord. Tack through the bridle leg and tie around the ribbon wire. Do not tack through the ribbon wire. (See Figure 3)

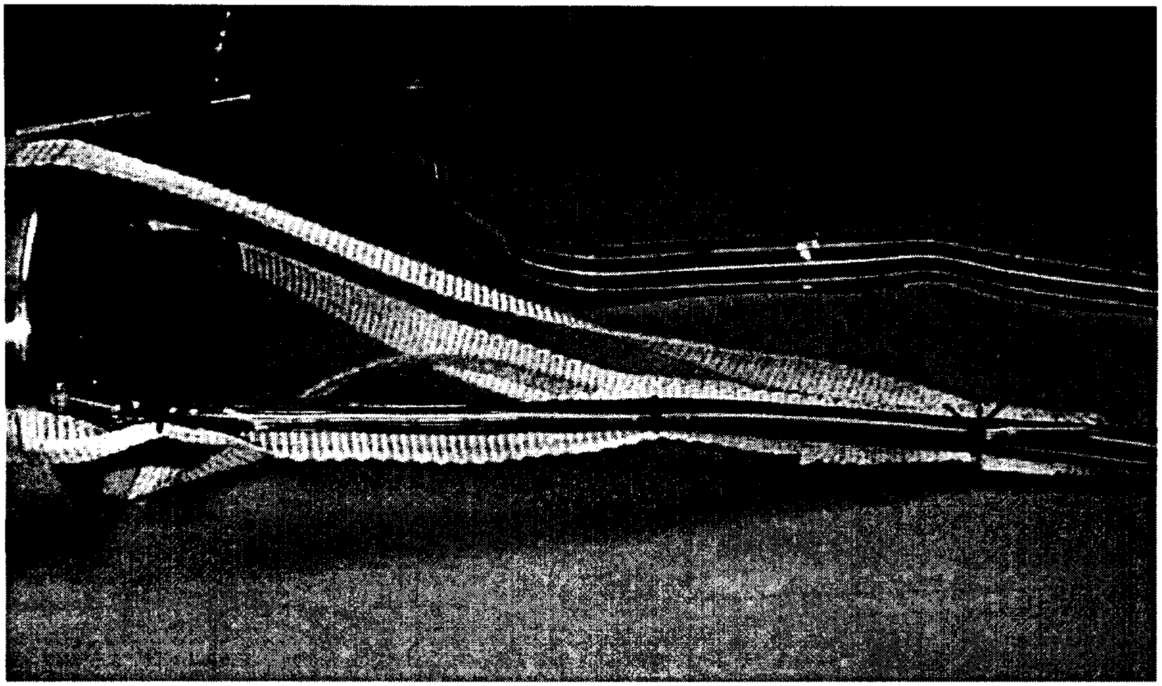


Figure 3

4. Remove the packing plate from the suspension line end of the main parachute pack.

5. Attach the loop of the TM bridle to the main parachute suspension line loop by performing the following steps:

   a. Cut an approximately 2-foot length of 4000 lb. breaking strength Kevlar braid.
   b. Pass the Kevlar braid through one of the main parachute lacing knife lanyards, then through the suspension line loop and then through the second lacing knife lanyard.
   c. Bring the loop of the TM bridle up to the main parachute suspension line loop.
   d. Pass each end of the Kevlar braid through the loop of the TM bridle from opposite directions.
   e. Bring the two ends of the Kevlar braid together and tie using a square knot with an overhand knot on each free end.
   f. Secure the two overhand knots by using one turn of waxed Size 5 nylon thread through both knots and tied using a square knot with an overhand knot on the free ends. (See Figure 4)

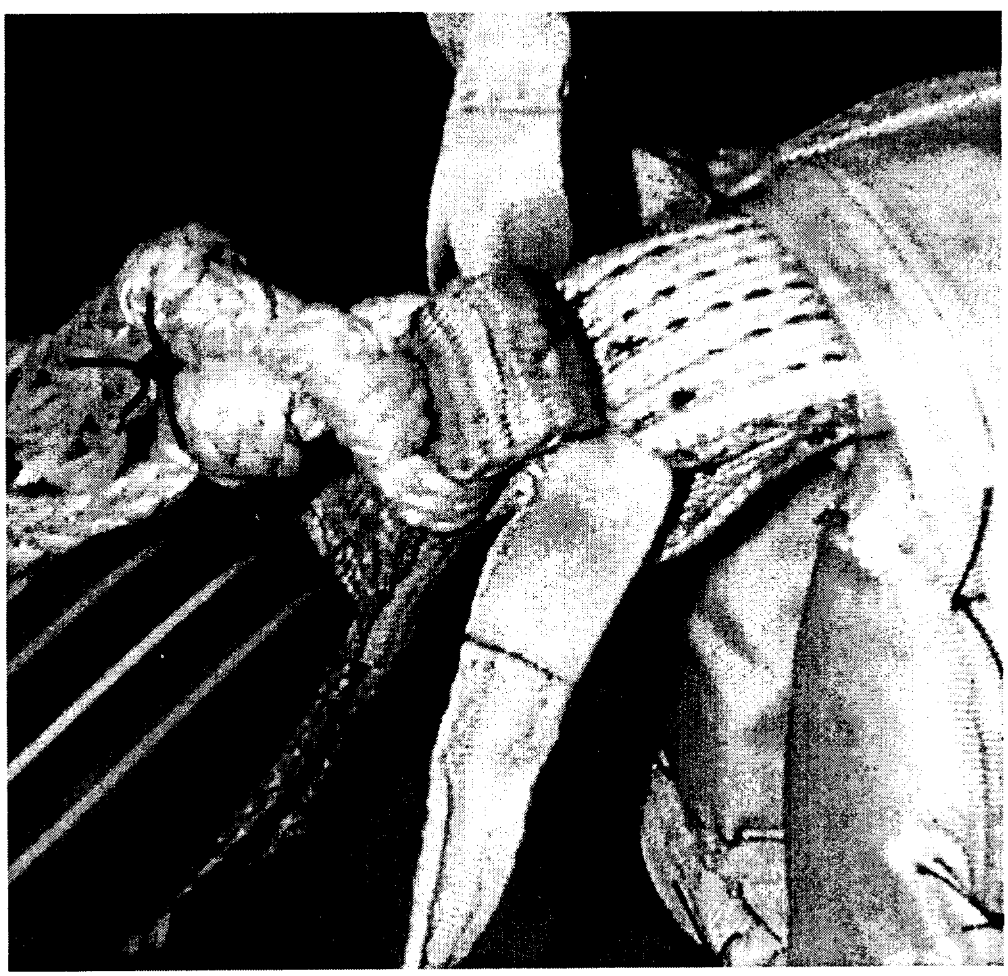


Figure 4

6. Insert the ribbon wire through the loop on the main parachute bag. Orient the wire with the blue wire on the left and the brown wire on the right when viewing the parachute in an upright position. (See Figure 5)

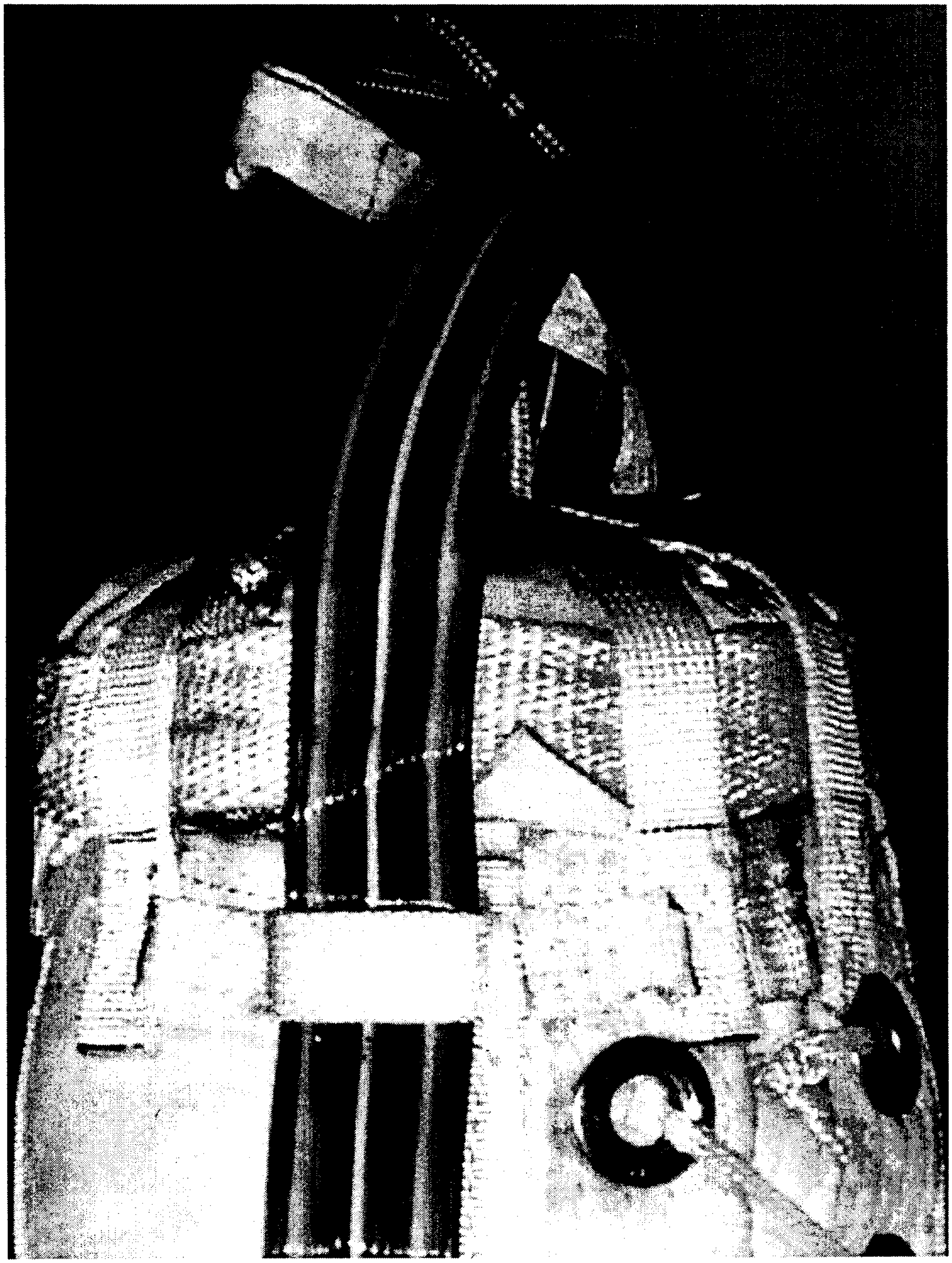


Figure 5

7. Attach the ribbon wire to the main parachute pack in two places using waxed Size 5 cord nylon thread. Make one attachment at the bottom of the pack (suspension line end) and the other attachment at the middle of the pack. Tack through the edges of the reinforcement webbing and then tie around the ribbon wire. Ensure that the tacks do not penetrate the main bag and the parachute within the pack. (See Figure 6)

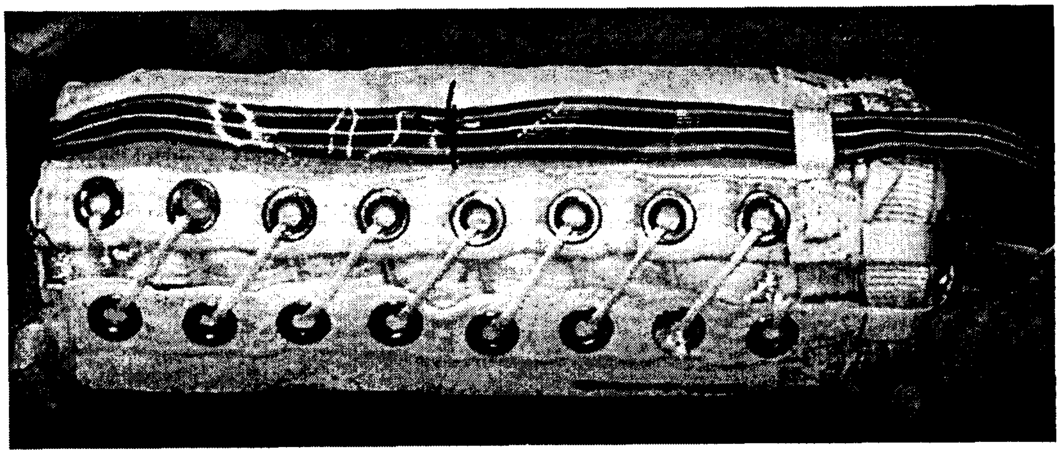


Figure 6

8. Fold the legs of the TM bridle as evenly as possible around the antenna of the TM pack. Move the TM pack against the parachute pack, inserting the antenna into the slot at the bottom of the parachute. (See Figure 7)

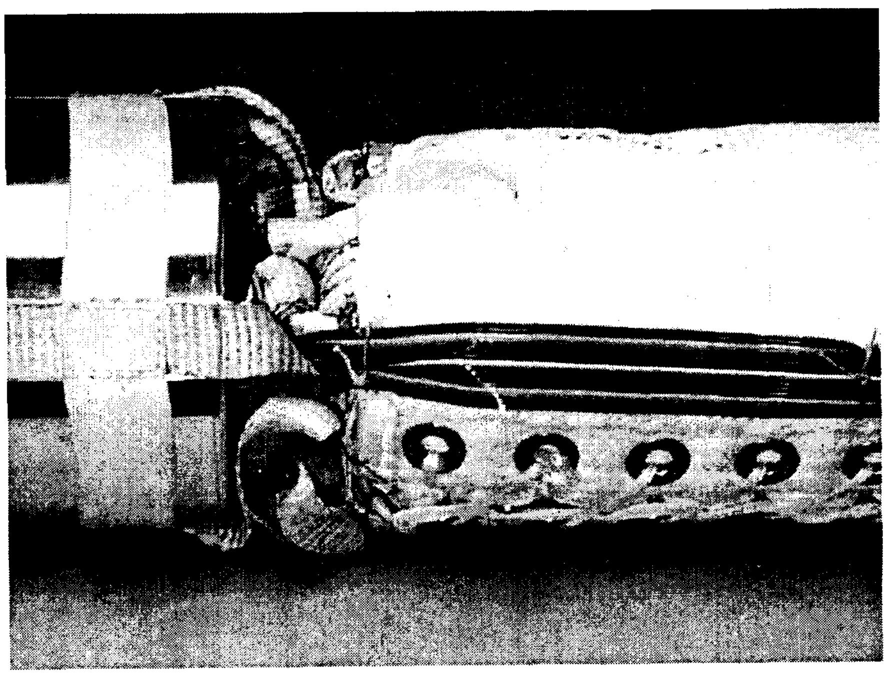


Figure 7

9. Place the tube in a horizontal position. Align the ribbon wire on the TM pack and parachute with its termination block on the tube. Insert the TM pack and parachute into the tube and slide in as far as possible. (See Figure 8)

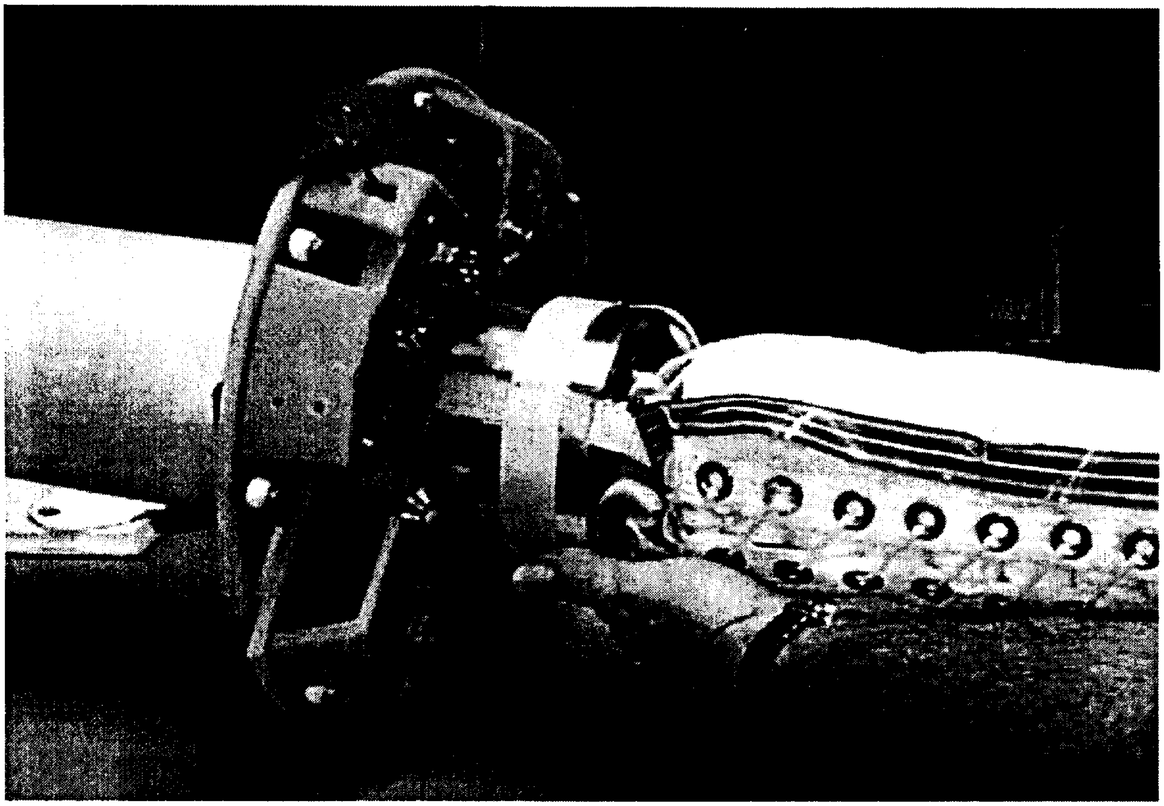


Figure 8

10. Return the tube with the TM pack and parachute to an upright position. (See Figure 9)

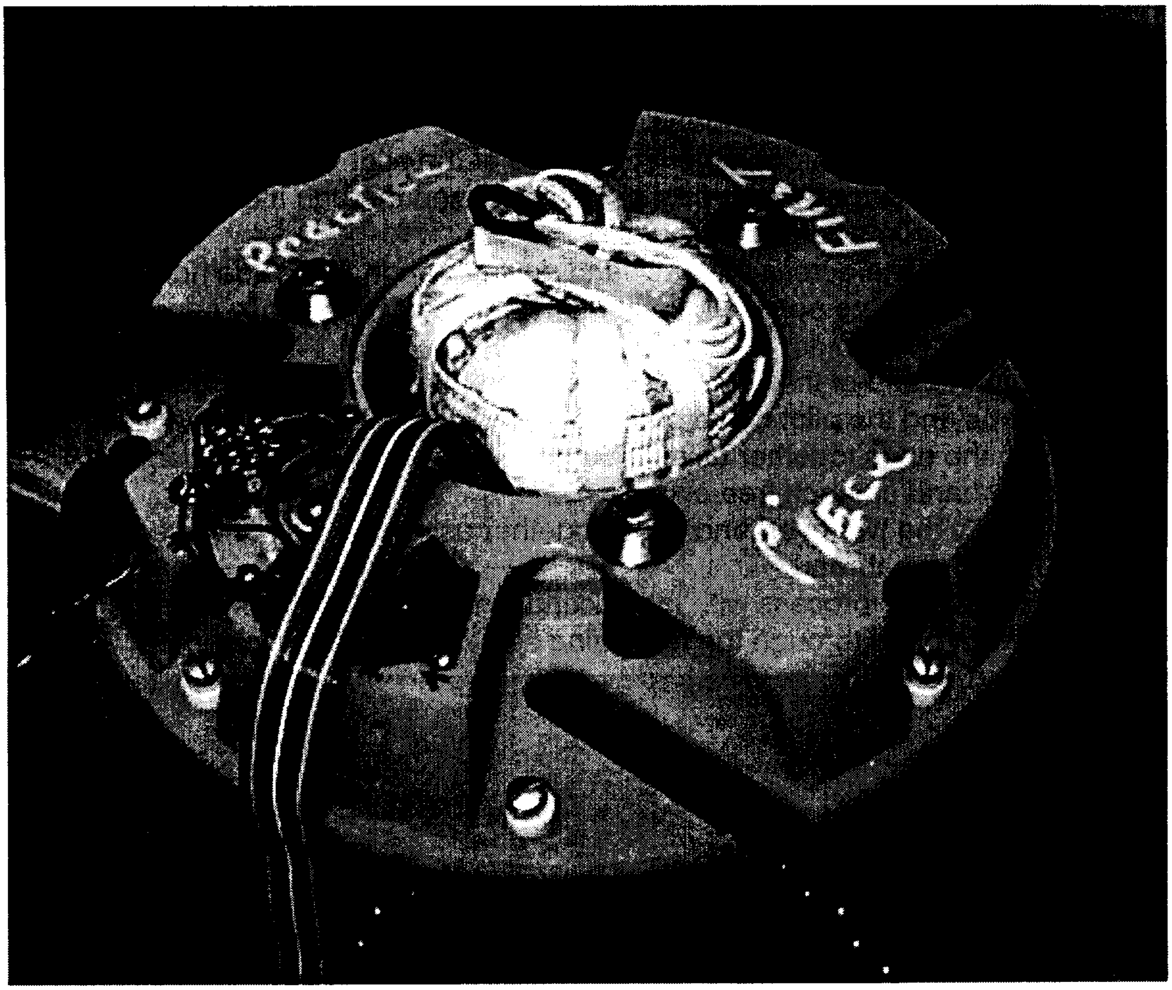


Figure 9

11. Restrain the parachute in the tube by performing the following steps: (see Figure 10)

   a. Cut two lengths of 1000-lb.-breaking-strength Kevlar braid. (approx. 3 ft. long)
   b. Pass one end of one length down through an outside hole of the support plate, then back up through the inside hole of the plate.
   c. Pass this end through the loop of one of the pilot chute release knives, through the loop of the pilot chute bridle and through the loop of the second pilot chute release knife.
   d. Run this line across the pack and down through the inside hole and back up through the outside hole of the two holes diametrically opposed to the original two holes.
   e. Run the end of this line back across the pack, passing through the knife loops and the pilot chute bridle loop again in the opposite direction.
   f. Tie the ends together using a surgeon's knot, a locking knot and an overhand on each free end.
   g. Safety the two overhand knots together using one turn of waxed Size 5 cord nylon thread.
   h. Repeat this process with the second length of 1000-lb.-breaking-strength Kevlar braid through the remaining sets of holes in the plate.

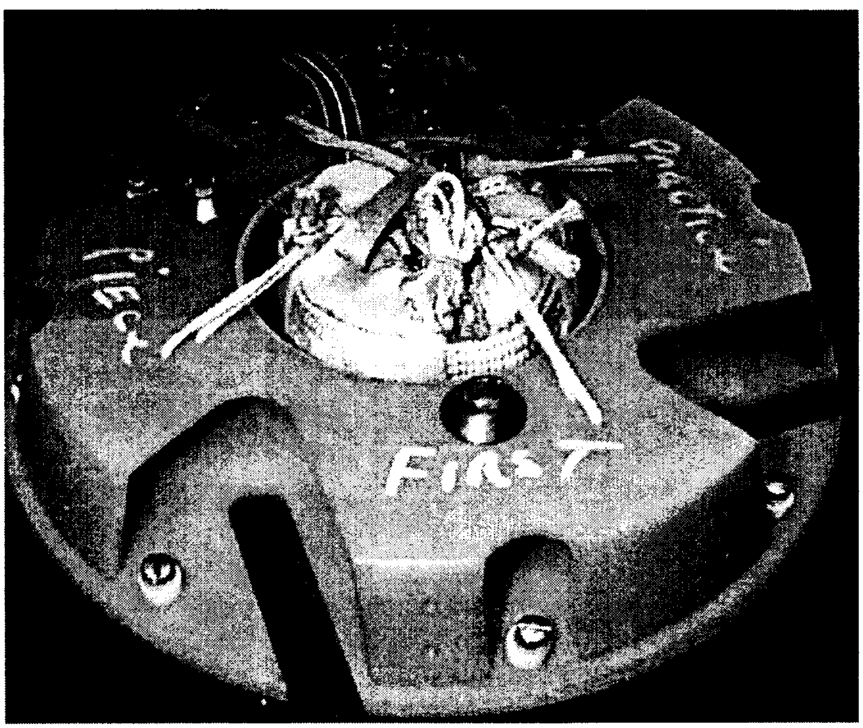


Figure 10

12. After the terminal board has been installed and the electrical connections made, secure the ribbon wire to the spring place in two places with a single turn of waxed Size 5 nylon thread. Tie tightly with a binder's knot and a square knot. Tie the free ends together with an overhand knot. (See Figure 11)

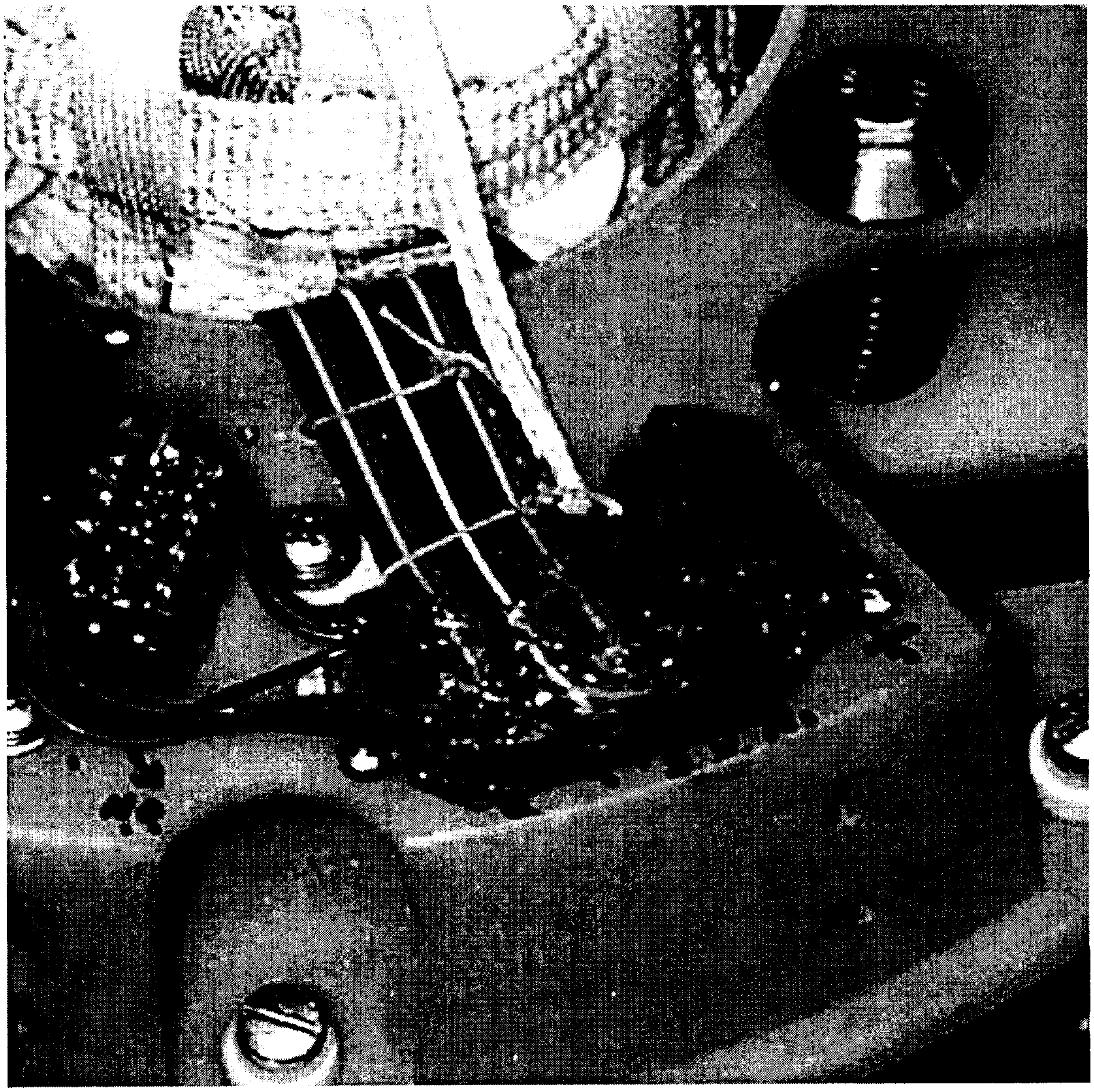


Figure 11

Appendix C

Nominal WBS Trajectory

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.000	0	0	0	0.0	900	0.0	Initiate Deployment Sequence
0.001	1	1	0	0.0	900	0.0	
0.002	2	2	0	0.0	900	0.0	
0.003	3	3	0	0.0	900	0.0	
0.004	4	4	0	0.0	900	0.0	
0.005	4	4	0	0.0	900	0.0	
0.006	5	5	0	0.0	900	0.0	
0.007	6	6	0	0.0	900	0.0	
0.008	7	7	0	0.0	900	0.0	
0.009	8	8	0	0.0	900	0.0	
0.010	9	9	0	0.0	900	0.0	
0.011	10	10	0	0.0	900	0.0	
0.012	11	11	0	0.0	900	0.0	
0.013	12	12	0	0.0	900	0.0	
0.014	13	13	0	0.0	900	0.0	
0.015	13	13	0	0.0	900	0.0	
0.016	14	14	0	0.0	900	0.0	
0.017	15	15	0	0.0	900	0.0	
0.018	16	16	0	0.0	900	0.0	
0.019	17	17	0	0.0	900	0.0	
0.020	18	18	0	0.0	900	0.0	
0.021	19	19	0	0.0	900	0.0	
0.022	20	20	0	0.0	900	0.0	
0.023	21	21	0	0.0	900	0.0	
0.024	22	22	0	0.0	900	0.0	
0.025	22	22	0	0.0	900	0.0	
0.026	23	23	0	0.0	900	0.0	
0.027	24	24	0	0.0	900	0.0	
0.028	25	25	0	0.0	900	0.0	
0.029	26	26	0	0.0	900	0.0	
0.030	27	27	0	0.0	900	0.0	
0.031	28	28	0	0.0	900	0.0	
0.032	29	29	0	0.0	900	0.0	
0.033	30	30	0	0.0	900	0.0	
0.034	31	31	0	0.0	900	0.0	
0.035	31	31	0	0.0	900	0.0	
0.036	32	32	0	0.0	900	0.0	
0.037	33	33	0	0.0	900	0.0	
0.038	34	34	0	0.0	900	0.0	
0.039	35	35	0	0.0	900	0.0	
0.040	36	36	0	0.0	900	0.0	
0.041	37	37	0	0.0	900	0.0	
0.042	38	38	0	0.0	900	0.0	
0.043	39	39	0	0.0	900	0.0	
0.044	40	40	0	0.0	900	0.0	
0.045	40	40	0	0.0	900	0.0	
0.046	41	41	0	0.0	900	0.0	
0.047	42	42	0	0.0	900	0.0	
0.048	43	43	0	0.0	900	0.0	
0.049	44	44	0	0.0	900	0.0	
0.050	45	45	0	0.0	900	0.0	
0.051	46	46	0	0.0	900	0.0	
0.052	47	47	0	0.0	900	0.0	
0.053	48	48	0	0.0	900	0.0	
0.054	49	49	0	0.0	900	0.0	
0.055	49	49	0	0.0	900	0.0	
0.056	50	50	0	0.0	900	0.0	
0.057	51	51	0	0.0	900	0.0	
0.058	52	52	0	0.0	900	0.0	
0.059	53	53	0	0.0	900	0.0	
0.060	54	54	0	0.0	900	0.0	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.061	55	55	0	0.0	900	0.0	
0.062	56	56	0	0.0	900	0.0	
0.063	57	57	0	0.0	900	0.0	
0.064	58	58	0	0.0	900	0.0	
0.065	58	58	0	0.0	900	0.0	
0.066	59	59	0	0.0	900	0.0	
0.067	60	60	0	0.0	900	0.0	
0.068	61	61	0	0.0	900	0.0	
0.069	62	62	0	0.0	900	0.0	
0.070	63	63	0	0.0	900	0.0	
0.071	64	64	0	0.0	900	0.0	
0.072	65	65	0	0.0	900	0.0	
0.073	66	66	0	0.0	900	0.0	
0.074	67	67	0	0.0	900	0.0	
0.075	68	68	0	0.0	900	0.0	
0.076	68	68	0	0.0	900	0.0	
0.077	69	69	0	0.0	900	0.0	
0.078	70	70	0	0.0	900	0.0	
0.079	71	71	0	0.0	900	0.0	
0.080	72	72	0	0.0	900	0.0	
0.081	73	73	0	0.0	900	0.0	
0.082	74	74	0	0.0	900	0.0	Pilot Chute @ Canopy Stretch
0.083	75	75	0	0.0	900	0.0	
0.084	76	76	0	0.0	900	0.0	
0.085	77	77	0	0.0	900	0.0	
0.086	77	77	0	0.0	900	0.0	
0.087	78	78	0	0.0	900	0.0	
0.088	79	79	0	0.0	900	0.0	
0.089	80	80	0	0.0	900	0.0	
0.090	81	81	0	0.0	900	0.0	
0.091	82	82	0	0.0	900	0.0	
0.092	83	83	0	0.0	900	0.0	
0.093	84	84	0	0.0	900	0.0	
0.094	85	85	0	0.0	900	0.0	
0.095	86	86	0	0.0	900	0.0	
0.096	86	86	0	0.0	900	0.0	
0.097	87	87	0	0.0	900	0.0	
0.098	88	88	0	0.0	900	0.0	
0.099	89	89	0	0.0	900	0.0	
0.100	90	90	0	0.0	900	0.0	Pilot Chute Canopy Fill
0.101	91	91	0	0.0	900	0.0	
0.102	92	92	0	0.0	900	0.0	
0.103	93	93	0	0.0	900	0.0	
0.104	94	94	0	0.0	900	0.0	
0.105	95	95	0	0.0	900	0.0	
0.106	95	95	0	0.0	900	0.0	
0.107	96	96	0	0.0	900	0.0	
0.108	97	97	0	0.0	900	0.0	
0.109	98	98	0	0.0	900	0.0	
0.110	99	99	0	0.0	900	0.0	
0.111	100	100	0	0.0	900	0.0	
0.112	101	101	0	0.0	900	0.0	
0.113	102	102	0	0.0	900	0.0	
0.114	103	103	0	0.0	900	0.0	
0.115	104	104	0	0.0	899	0.0	
0.116	104	104	0	0.0	899	0.0	
0.117	105	105	0	0.0	899	0.0	
0.118	106	106	0	0.0	899	0.0	
0.119	107	107	0	0.0	899	0.0	
0.120	108	108	0	0.0	899	0.0	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.121	109	109	0	0.0	898	0.0	
0.122	110	110	0	0.0	898	0.0	
0.123	111	111	0	0.0	898	0.0	
0.124	112	112	0	0.0	898	0.0	
0.125	113	113	0	0.0	897	0.0	
0.126	113	113	0	0.0	897	0.0	
0.127	114	114	0	0.0	897	0.0	
0.128	115	115	0	0.0	896	0.0	
0.129	116	116	0	0.0	896	0.0	
0.130	117	117	0	0.0	896	0.0	
0.131	118	118	0	0.0	895	0.0	
0.132	119	119	0	0.0	895	0.0	
0.133	120	120	0	0.0	895	0.0	
0.134	121	121	0	0.0	894	0.0	
0.135	122	121	0	0.0	894	0.0	
0.136	122	122	0	0.0	893	0.0	
0.137	123	123	0	0.0	893	0.0	
0.138	124	124	0	0.0	893	0.0	
0.139	125	125	0	0.0	892	0.0	
0.140	126	126	0	0.0	892	0.0	
0.141	127	127	0	0.0	891	0.0	
0.142	128	128	0	0.0	891	0.0	
0.143	129	129	0	0.0	890	0.0	
0.144	130	130	0	0.0	890	0.0	
0.145	131	130	0	0.0	889	0.0	
0.146	131	131	0	0.0	888	0.0	
0.147	132	132	0	0.0	888	0.0	
0.148	133	133	0	0.0	887	0.0	
0.149	134	134	0	0.0	887	0.0	
0.150	135	135	0	0.0	886	0.0	
0.151	136	136	0	0.0	885	0.0	
0.152	137	137	0	0.0	885	0.0	
0.153	138	137	0	0.0	884	0.0	
0.154	139	138	0	0.0	883	0.0	
0.155	140	139	0	0.0	883	0.0	
0.156	140	140	0	0.0	882	0.0	
0.157	141	141	0	0.0	881	0.0	
0.158	142	142	0	0.0	881	0.0	
0.159	143	143	0	0.0	880	0.0	
0.160	144	144	0	0.0	879	0.0	
0.161	145	145	0	0.0	878	0.0	
0.162	146	145	0	0.0	878	0.0	
0.163	147	146	0	0.0	873	0.0	
0.164	148	147	1	0.0	869	0.0	
0.165	149	148	1	0.0	865	0.0	
0.166	149	149	1	0.0	861	0.0	
0.167	150	150	1	0.0	857	0.0	
0.168	151	151	1	0.0	853	0.0	
0.169	152	151	1	0.0	850	0.0	
0.170	153	152	1	0.0	846	0.0	
0.171	154	153	1	0.0	842	0.0	
0.172	155	154	1	0.0	838	0.0	
0.173	156	155	1	0.0	834	0.0	Main Parachute @ Canopy Stretch
0.174	157	156	1	0.0	817	0.9	
0.175	157	156	1	0.6	815	1.3	
0.176	158	157	1	0.8	811	1.6	
0.177	159	158	1	1.0	808	2.0	
0.178	160	159	1	1.2	803	2.4	
0.179	161	160	1	1.3	798	2.7	
0.180	162	160	2	1.5	792	3.1	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.181	163	161	2	1.6	786	3.5	
0.182	164	162	2	1.7	779	3.8	
0.183	165	163	2	1.8	772	4.2	
0.184	166	164	2	1.9	764	4.5	
0.185	166	164	2	2.0	756	4.9	
0.186	167	165	2	2.0	748	5.2	
0.187	168	166	3	2.1	739	5.6	
0.188	169	166	3	2.2	729	5.9	
0.189	170	167	3	2.3	720	6.2	
0.190	171	168	3	2.3	710	6.6	
0.191	172	169	3	2.4	700	6.9	
0.192	173	169	3	2.5	690	7.2	
0.193	174	170	4	2.5	680	7.5	
0.194	175	171	4	2.6	669	7.8	
0.195	175	171	4	2.6	659	8.1	
0.196	176	172	4	2.7	648	8.4	
0.197	177	173	5	2.7	638	8.7	
0.198	178	173	5	2.8	627	9.0	
0.199	179	174	5	2.8	617	9.3	
0.200	180	175	5	2.9	606	9.6	
0.201	181	175	6	2.9	596	9.9	
0.202	182	176	6	3.0	585	10.1	
0.203	183	176	6	3.0	575	10.4	
0.204	184	177	7	3.1	565	10.7	
0.205	184	177	7	3.1	555	10.9	
0.206	185	178	7	3.1	545	11.2	
0.207	186	179	8	3.2	535	11.4	
0.208	187	179	8	3.2	526	11.7	
0.209	188	180	9	3.3	516	11.9	
0.210	189	180	9	3.3	507	12.1	
0.211	190	181	9	3.3	498	12.4	
0.212	191	181	10	3.4	489	12.6	
0.213	192	182	10	3.4	480	12.8	
0.214	193	182	11	3.4	472	13.0	
0.215	193	183	11	3.5	463	13.3	
0.216	194	183	11	3.5	455	13.5	
0.217	195	184	12	3.5	447	13.7	
0.218	196	184	12	3.5	439	13.9	
0.219	197	184	13	3.6	431	14.1	
0.220	198	185	13	3.6	424	14.3	
0.221	199	185	14	3.6	416	14.5	
0.222	200	186	14	3.6	409	14.7	
0.223	201	186	15	3.7	402	14.9	
0.224	202	186	15	3.7	395	15.0	
0.225	203	187	16	3.7	388	15.2	
0.226	203	187	16	3.7	382	15.4	
0.227	204	188	17	3.8	375	15.6	
0.228	205	188	17	3.8	369	15.7	
0.229	206	188	18	3.8	363	15.9	
0.230	207	189	18	3.8	357	16.1	
0.231	208	189	19	3.8	351	16.2	
0.232	209	189	19	3.9	345	16.4	
0.233	210	190	20	3.9	340	16.6	
0.234	211	190	21	3.9	335	16.7	
0.235	212	190	21	3.9	329	16.9	
0.236	212	191	22	3.9	324	17.0	
0.237	213	191	22	4.0	319	17.2	
0.238	214	191	23	4.0	314	17.3	
0.239	215	192	23	4.0	309	17.5	
0.240	216	192	24	4.0	305	17.6	
0.241	217	192	25	4.0	300	17.7	
0.242	218	193	25	4.0	295	17.9	
0.243	219	193	26	4.1	291	18.0	
0.244	220	193	26	4.1	287	18.1	
0.245	221	193	27	4.1	283	18.3	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.246	221	194	28	4.1	279	18.4	
0.247	222	194	28	4.1	275	18.5	
0.248	223	194	29	4.1	271	18.6	
0.249	224	195	30	4.1	267	18.8	
0.250	225	195	30	4.2	263	18.9	
0.251	226	195	31	4.2	260	19.0	
0.252	227	195	32	4.2	256	19.1	
0.253	228	196	32	4.2	253	19.2	
0.254	229	196	33	4.2	249	19.4	
0.255	230	196	33	4.2	246	19.5	
0.256	230	196	34	4.2	243	19.6	
0.257	231	197	35	4.3	239	19.7	
0.258	232	197	35	4.3	236	19.8	
0.259	233	197	36	4.3	233	19.9	
0.260	234	197	37	4.3	230	20.0	
0.261	235	197	37	4.3	228	20.1	
0.262	236	198	38	4.3	225	20.2	
0.263	237	198	39	4.3	222	20.3	
0.264	238	198	39	4.3	219	20.4	
0.265	239	198	40	4.3	217	20.5	
0.266	239	199	41	4.4	214	20.6	
0.267	240	199	42	4.4	211	20.7	
0.268	241	199	42	4.4	209	20.8	
0.269	242	199	43	4.4	206	20.9	
0.270	243	199	44	4.4	204	21.0	
0.271	244	200	44	4.4	202	21.1	
0.272	245	200	45	4.4	199	21.2	
0.273	246	200	46	4.4	197	21.3	
0.274	247	200	46	4.4	195	21.4	
0.275	248	200	47	4.5	193	21.5	
0.276	248	201	48	4.5	191	21.6	
0.277	249	201	49	4.5	189	21.6	
0.278	250	201	49	4.5	187	21.7	
0.279	251	201	50	4.5	185	21.8	
0.280	252	201	51	4.5	183	21.9	
0.281	253	202	51	4.5	181	22.0	
0.282	254	202	52	4.5	179	22.1	
0.283	255	202	53	4.5	177	22.1	
0.284	256	202	54	4.5	175	22.2	
0.285	257	202	54	4.5	174	22.3	
0.286	257	202	55	4.5	172	22.4	
0.287	258	203	56	4.6	170	22.5	
0.288	259	203	56	4.6	169	22.5	
0.289	260	203	57	4.6	167	22.6	
0.290	261	203	58	4.6	165	22.7	
0.291	262	203	59	4.6	164	22.8	
0.292	263	203	59	4.6	162	22.8	
0.293	264	204	60	4.6	161	22.9	
0.294	265	204	61	4.6	159	23.0	
0.295	266	204	62	4.6	158	23.1	
0.296	266	204	62	4.6	156	23.1	
0.297	267	204	63	4.6	155	23.2	
0.298	268	204	64	4.6	153	23.3	
0.299	269	205	65	4.7	152	23.3	
0.300	270	205	65	4.7	151	23.4	
0.301	271	205	66	4.7	149	23.5	
0.302	272	205	67	4.7	148	23.6	
0.303	273	205	68	4.7	147	23.6	
0.304	274	205	68	4.7	146	23.7	
0.305	275	205	69	4.7	144	23.8	
0.306	275	206	70	4.7	143	23.8	
0.307	276	206	71	4.7	142	23.9	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.308	277	206	71	4.7	141	23.9	
0.309	278	206	72	4.7	140	24.0	
0.310	279	206	73	4.7	139	24.1	
0.311	280	206	74	4.7	137	24.1	
0.312	281	206	74	4.7	136	24.2	
0.313	282	207	75	4.7	135	24.3	
0.314	283	207	76	4.8	134	24.3	
0.315	284	207	77	4.8	133	24.4	
0.316	284	207	78	4.8	132	24.4	
0.317	285	207	78	4.8	131	24.5	
0.318	286	207	79	4.8	130	24.6	
0.319	287	207	80	4.8	129	24.6	
0.320	288	208	81	4.8	128	24.7	
0.321	289	208	81	4.8	127	24.7	
0.322	290	208	82	4.8	126	24.8	
0.323	291	208	83	4.8	125	24.9	
0.324	292	208	84	4.8	125	24.9	
0.325	293	208	84	4.8	124	25.0	
0.326	294	208	85	4.8	123	25.0	
0.327	294	208	86	4.8	122	25.1	
0.328	295	209	87	4.8	121	25.1	
0.329	296	209	88	4.8	120	25.2	
0.330	297	209	88	4.8	119	25.2	
0.331	298	209	89	4.8	119	25.3	
0.332	299	209	90	4.9	118	25.4	
0.333	300	209	91	4.9	117	25.4	
0.334	301	209	92	4.9	116	25.5	
0.335	302	209	92	4.9	116	25.5	
0.336	303	209	93	4.9	115	25.6	
0.337	303	210	94	4.9	114	25.6	
0.338	304	210	95	4.9	113	25.7	
0.339	305	210	95	4.9	113	25.7	
0.340	306	210	96	4.9	112	25.8	
0.341	307	210	97	4.9	111	25.8	
0.342	308	210	98	4.9	111	25.9	
0.343	309	210	99	4.9	110	25.9	
0.344	310	210	99	4.9	109	26.0	
0.345	311	211	100	4.9	109	26.0	
0.346	312	211	101	4.9	108	26.1	
0.347	312	211	102	4.9	107	26.1	
0.348	313	211	103	4.9	107	26.2	
0.349	314	211	103	4.9	106	26.2	
0.350	315	211	104	4.9	105	26.3	
0.351	316	211	105	4.9	105	26.3	
0.352	317	211	106	5.0	104	26.4	
0.353	318	211	107	5.0	104	26.4	
0.354	319	211	107	5.0	103	26.5	
0.355	320	212	108	5.0	102	26.5	
0.356	321	212	109	5.0	102	26.6	
0.357	321	212	110	5.0	101	26.6	
0.358	322	212	111	5.0	101	26.6	
0.359	323	212	111	5.0	100	26.7	
0.360	324	212	112	5.0	100	26.7	
0.361	325	212	113	5.0	99	26.8	
0.362	326	212	114	5.0	99	26.8	
0.363	327	212	115	5.0	98	26.9	
0.364	328	212	115	5.0	98	26.9	
0.365	329	213	116	5.0	97	27.0	
0.366	330	213	117	5.0	97	27.0	
0.367	330	213	118	5.0	96	27.0	
0.368	331	213	119	5.0	96	27.1	
0.369	332	213	119	5.0	95	27.1	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.370	333	213	120	5.0	95	27.2	
0.371	334	213	121	5.0	94	27.2	
0.372	335	213	122	5.0	94	27.3	
0.373	336	213	123	5.0	93	27.3	
0.374	337	213	123	5.0	93	27.3	
0.375	338	214	124	5.1	92	27.4	
0.376	339	214	125	5.1	92	27.4	
0.377	339	214	126	5.1	92	27.5	
0.378	340	214	127	5.1	91	27.5	
0.379	341	214	127	5.1	91	27.6	
0.380	342	214	128	5.1	90	27.6	
0.381	343	214	129	5.1	90	27.6	
0.382	344	214	130	5.1	90	27.7	
0.383	345	214	131	5.1	89	27.7	
0.384	346	214	131	5.1	89	27.8	
0.385	347	214	132	5.1	88	27.8	
0.386	348	215	133	5.1	88	27.8	
0.387	348	215	134	5.1	88	27.9	
0.388	349	215	135	5.1	87	27.9	
0.389	350	215	136	5.1	87	28.0	
0.390	351	215	136	5.1	87	28.0	
0.391	352	215	137	5.1	86	28.0	
0.392	353	215	138	5.1	86	28.1	
0.393	354	215	139	5.1	85	28.1	
0.394	355	215	140	5.1	85	28.2	
0.395	356	215	140	5.1	85	28.2	
0.396	357	215	141	5.1	84	28.2	
0.397	357	215	142	5.1	84	28.3	
0.398	358	216	143	5.1	84	28.3	
0.399	359	216	144	5.1	83	28.3	
0.400	360	216	145	5.1	83	28.4	
0.401	361	216	145	5.1	83	28.4	
0.402	362	216	146	5.2	82	28.5	
0.403	363	216	147	5.2	82	28.5	
0.404	364	216	148	5.2	82	28.5	
0.405	365	216	149	5.2	82	28.6	
0.406	366	216	149	5.2	81	28.6	
0.407	366	216	150	5.2	81	28.6	
0.408	367	216	151	5.2	81	28.7	
0.409	368	216	152	5.2	80	28.7	
0.410	369	217	153	5.2	80	28.8	
0.411	370	217	154	5.2	80	28.8	
0.412	371	217	154	5.2	80	28.8	
0.413	372	217	155	5.2	79	28.9	
0.414	373	217	156	5.2	79	28.9	
0.415	374	217	157	5.2	79	28.9	
0.416	375	217	158	5.2	78	29.0	
0.417	376	217	158	5.2	78	29.0	
0.418	376	217	159	5.2	78	29.0	
0.419	377	217	160	5.2	78	29.1	
0.420	378	217	161	5.2	77	29.1	
0.421	379	217	162	5.2	77	29.1	
0.422	380	217	163	5.2	77	29.2	
0.423	381	218	163	5.2	77	29.2	
0.424	382	218	164	5.2	76	29.3	
0.425	383	218	165	5.2	76	29.3	
0.426	384	218	166	5.2	76	29.3	
0.427	385	218	167	5.2	76	29.4	
0.428	385	218	168	5.2	75	29.4	
0.429	386	218	168	5.2	75	29.4	
0.430	387	218	169	5.2	75	29.5	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.431	388	218	170	5.2	75	29.5	
0.432	389	218	171	5.3	75	29.5	
0.433	390	218	172	5.3	74	29.6	
0.434	391	218	172	5.3	74	29.6	
0.435	392	218	173	5.3	74	29.6	
0.436	393	219	174	5.3	74	29.7	
0.437	394	219	175	5.3	73	29.7	
0.438	394	219	176	5.3	73	29.7	
0.439	395	219	177	5.3	73	29.8	
0.440	396	219	177	5.3	73	29.8	
0.441	397	219	178	5.3	73	29.8	
0.442	398	219	179	5.3	72	29.9	
0.443	399	219	180	5.3	72	29.9	
0.444	400	219	181	5.3	72	29.9	
0.445	401	219	182	5.3	72	30.0	
0.446	402	219	182	5.3	72	30.0	
0.447	403	219	183	5.3	71	30.0	
0.448	404	219	184	5.3	71	30.1	
0.449	404	219	185	5.3	71	30.1	
0.450	405	220	186	5.3	71	30.1	
0.451	406	220	187	5.3	71	30.2	
0.452	407	220	187	5.3	70	30.2	
0.453	408	220	188	5.3	70	30.2	
0.454	409	220	189	5.3	70	30.2	
0.455	410	220	190	5.3	70	30.3	
0.456	411	220	191	5.3	70	30.3	
0.457	412	220	192	5.3	70	30.3	
0.458	413	220	192	5.3	69	30.4	
0.459	413	220	193	5.3	69	30.4	
0.460	414	220	194	5.3	69	30.4	
0.461	415	220	195	5.3	69	30.5	
0.462	416	220	196	5.3	69	30.5	
0.463	417	220	197	5.3	69	30.5	
0.464	418	221	197	5.3	68	30.6	
0.465	419	221	198	5.3	68	30.6	
0.466	420	221	199	5.4	68	30.6	
0.467	421	221	200	5.4	68	30.7	
0.468	422	221	201	5.4	68	30.7	
0.469	422	221	202	5.4	68	30.7	
0.470	423	221	202	5.4	67	30.7	
0.471	424	221	203	5.4	67	30.8	
0.472	425	221	204	5.4	67	30.8	
0.473	426	221	205	5.4	67	30.8	
0.474	427	221	206	5.4	67	30.9	
0.475	428	221	207	5.4	67	30.9	
0.476	429	221	207	5.4	66	30.9	
0.477	430	221	208	5.4	66	31.0	
0.478	431	222	209	5.4	66	31.0	
0.479	432	222	210	5.4	66	31.0	
0.480	432	222	211	5.4	66	31.0	
0.481	433	222	212	5.4	66	31.1	
0.482	434	222	212	5.4	66	31.1	
0.483	435	222	213	5.4	66	31.1	
0.484	436	222	214	5.4	65	31.2	
0.485	437	222	215	5.4	65	31.2	
0.486	438	222	216	5.4	65	31.2	
0.487	439	222	217	5.4	65	31.3	
0.488	440	222	217	5.4	65	31.3	
0.489	441	222	218	5.4	65	31.3	
0.490	441	222	219	5.4	65	31.3	
0.491	442	222	220	5.4	65	31.4	
0.492	443	222	221	5.4	64	31.4	
0.493	444	223	222	5.4	64	31.4	
0.494	445	223	222	5.4	64	31.5	
0.495	446	223	223	5.4	64	31.5	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.496	447	223	224	5.4	64	31.5	
0.497	448	223	225	5.4	64	31.5	
0.498	449	223	226	5.4	64	31.6	
0.499	450	223	227	5.4	64	31.6	
0.500	450	223	227	5.4	63	31.6	
0.501	451	223	228	5.4	63	31.7	
0.502	452	223	229	5.4	63	31.7	
0.503	453	223	230	5.4	63	31.7	
0.504	454	223	231	5.5	63	31.8	
0.505	455	223	232	5.5	63	31.8	
0.506	456	223	232	5.5	63	31.8	
0.507	457	223	233	5.5	63	31.8	
0.508	458	223	234	5.5	63	31.9	
0.509	459	224	235	5.5	62	31.9	
0.510	459	224	236	5.5	62	31.9	
0.511	460	224	237	5.5	62	31.9	
0.512	461	224	238	5.5	62	32.0	
0.513	462	224	238	5.5	62	32.0	
0.514	463	224	239	5.5	62	32.0	
0.515	464	224	240	5.5	62	32.1	
0.516	465	224	241	5.5	62	32.1	
0.517	466	224	242	5.5	62	32.1	
0.518	467	224	243	5.5	62	32.1	
0.519	468	224	243	5.5	61	32.2	
0.520	468	224	244	5.5	61	32.2	
0.521	469	224	245	5.5	61	32.2	
0.522	470	224	246	5.5	61	32.3	
0.523	471	224	247	5.5	61	32.3	
0.524	472	224	248	5.5	61	32.3	
0.525	473	225	248	5.5	61	32.3	
0.526	474	225	249	5.5	61	32.4	
0.527	475	225	250	5.5	61	32.4	
0.528	476	225	251	5.5	61	32.4	
0.529	477	225	252	5.5	61	32.4	
0.530	477	225	253	5.5	60	32.5	
0.531	478	225	253	5.5	60	32.5	
0.532	479	225	254	5.5	60	32.5	
0.533	480	225	255	5.5	60	32.6	
0.534	481	225	256	5.5	60	32.6	
0.535	482	225	257	5.5	60	32.6	
0.536	483	225	258	5.5	60	32.6	
0.537	484	225	259	5.5	60	32.7	
0.538	485	225	259	5.5	60	32.7	
0.539	486	225	260	5.5	60	32.7	
0.540	486	225	261	5.5	60	32.7	
0.541	487	226	262	5.5	59	32.8	
0.542	488	226	263	5.5	59	32.8	
0.543	489	226	264	5.5	59	32.8	
0.544	490	226	264	5.5	59	32.9	
0.545	491	226	265	5.6	59	32.9	
0.546	492	226	266	5.6	59	32.9	
0.547	493	226	267	5.6	59	32.9	
0.548	494	226	268	5.6	59	33.0	
0.549	495	226	269	5.6	59	33.0	
0.550	496	226	269	5.6	59	33.0	
0.551	496	226	270	5.6	59	33.0	
0.552	497	226	271	5.6	59	33.1	
0.553	498	226	272	5.6	59	33.1	
0.554	499	226	273	5.6	58	33.1	
0.555	500	226	274	5.6	58	33.1	
0.556	501	226	275	5.6	58	33.2	
0.557	502	227	275	5.6	58	33.2	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.558	503	227	276	5.6	58	33.2	
0.559	504	227	277	5.6	58	33.3	
0.560	505	227	278	5.6	58	33.3	
0.561	505	227	279	5.6	58	33.3	
0.562	506	227	280	5.6	58	33.3	
0.563	507	227	280	5.6	58	33.4	
0.564	508	227	281	5.6	58	33.4	
0.565	509	227	282	5.6	58	33.4	
0.566	510	227	283	5.6	58	33.4	
0.567	511	227	284	5.6	58	33.5	
0.568	512	227	285	5.6	57	33.5	
0.569	513	227	286	5.6	57	33.5	
0.570	514	227	286	5.6	57	33.5	
0.571	515	227	287	5.6	57	33.6	
0.572	515	227	288	5.6	57	33.6	
0.573	516	227	289	5.6	57	33.6	
0.574	517	228	290	5.6	57	33.6	
0.575	518	227	291	5.6	57	33.7	
0.576	519	228	291	5.6	57	33.7	
0.577	520	228	292	5.6	57	33.7	
0.578	521	228	293	5.6	57	33.7	
0.579	522	228	294	5.6	57	33.8	
0.580	523	228	295	5.6	57	33.8	
0.581	524	228	296	5.6	57	33.8	
0.582	524	228	296	5.6	57	33.9	
0.583	525	228	297	5.6	57	33.9	
0.584	526	228	298	5.6	57	33.9	
0.585	527	228	299	5.6	56	33.9	
0.586	528	228	300	5.6	56	34.0	
0.587	529	228	301	5.6	56	34.0	
0.588	530	228	302	5.6	56	34.0	
0.589	531	228	302	5.6	56	34.0	
0.590	532	228	303	5.7	56	34.1	
0.591	533	228	304	5.7	56	34.1	
0.592	533	229	305	5.7	56	34.1	
0.593	534	229	306	5.7	56	34.1	
0.594	535	229	307	5.7	56	34.2	
0.595	536	229	307	5.7	56	34.2	
0.596	537	229	308	5.7	56	34.2	
0.597	538	229	309	5.7	56	34.2	
0.598	539	229	310	5.7	56	34.3	
0.599	540	229	311	5.7	56	34.3	
0.600	541	229	312	5.7	56	34.3	
0.601	542	229	313	5.7	56	34.3	
0.602	542	229	313	5.7	56	34.4	
0.603	543	229	314	5.7	56	34.4	
0.604	544	229	315	5.7	55	34.4	
0.605	545	229	316	5.7	55	34.4	
0.606	546	229	317	5.7	55	34.5	
0.607	547	229	318	5.7	55	34.5	
0.608	548	229	318	5.7	55	34.5	
0.609	549	229	319	5.7	55	34.5	
0.610	550	230	320	5.7	55	34.6	
0.611	551	230	321	5.7	55	34.6	
0.612	551	230	322	5.7	55	34.6	
0.613	552	230	323	5.7	55	34.6	
0.614	553	230	324	5.7	55	34.7	
0.615	554	230	324	5.7	55	34.7	
0.616	555	230	325	5.7	55	34.7	
0.617	556	230	326	5.7	55	34.7	
0.618	557	230	327	5.7	55	34.8	
0.619	558	230	328	5.7	55	34.8	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.620	559	230	329	5.7	55	34.8	
0.621	560	230	329	5.7	55	34.8	
0.622	560	230	330	5.7	55	34.9	
0.623	561	230	331	5.7	54	34.9	
0.624	562	230	332	5.7	54	34.9	
0.625	563	230	333	5.7	54	34.9	
0.626	564	230	334	5.7	54	35.0	
0.627	565	231	335	5.7	54	35.0	
0.628	566	231	335	5.7	54	35.0	
0.629	567	231	336	5.7	54	35.0	
0.630	568	231	337	5.7	54	35.1	
0.631	569	231	338	5.7	54	35.1	
0.632	570	231	339	5.7	54	35.1	
0.633	570	231	340	5.7	54	35.1	
0.634	571	231	340	5.7	54	35.2	
0.635	572	231	341	5.7	54	35.2	
0.636	573	231	342	5.7	54	35.2	
0.637	574	231	343	5.8	54	35.2	
0.638	575	231	344	5.8	54	35.3	
0.639	576	231	345	5.8	54	35.3	
0.640	577	231	346	5.8	54	35.3	
0.641	578	231	346	5.8	54	35.3	
0.642	579	231	347	5.8	54	35.3	
0.643	580	231	348	5.8	54	35.4	
0.644	580	231	349	5.8	54	35.4	
0.645	581	231	350	5.8	54	35.4	
0.646	582	232	351	5.8	54	35.4	
0.647	583	232	352	5.8	53	35.5	
0.648	584	232	352	5.8	53	35.5	
0.649	585	232	353	5.8	53	35.5	
0.650	586	232	354	5.8	53	35.5	
0.651	587	232	355	5.8	53	35.6	
0.652	588	232	356	5.8	53	35.6	
0.653	589	232	357	5.8	53	35.6	
0.654	589	232	357	5.8	53	35.6	
0.655	590	232	358	5.8	53	35.7	
0.656	591	232	359	5.8	53	35.7	
0.657	592	232	360	5.8	53	35.7	
0.658	593	232	361	5.8	53	35.7	
0.659	594	232	362	5.8	53	35.8	
0.660	595	232	363	5.8	53	35.8	
0.661	596	232	363	5.8	53	35.8	
0.662	597	232	364	5.8	53	35.8	
0.663	598	232	365	5.8	53	35.9	
0.664	598	233	366	5.8	53	35.9	
0.665	599	233	367	5.8	53	35.9	
0.666	600	233	368	5.8	53	35.9	
0.667	601	233	368	5.8	53	36.0	
0.668	602	233	369	5.8	53	36.0	
0.669	603	233	370	5.8	53	36.0	
0.670	604	233	371	5.8	53	36.0	
0.671	605	233	372	5.8	53	36.0	
0.672	606	233	373	5.8	53	36.1	
0.673	607	233	374	5.8	53	36.1	
0.674	608	233	374	5.8	53	36.1	
0.675	608	233	375	5.8	52	36.1	
0.676	609	233	376	5.8	53	36.2	
0.677	610	233	377	5.8	53	36.2	
0.678	611	233	378	5.8	52	36.2	
0.679	612	233	379	5.8	52	36.2	
0.680	613	233	380	5.8	52	36.3	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.681	614	233	380	5.8	52	36.3	
0.682	615	234	381	5.8	52	36.3	
0.683	616	234	382	5.8	52	36.3	
0.684	617	234	383	5.8	52	36.4	
0.685	617	234	384	5.8	52	36.4	
0.686	618	234	385	5.8	52	36.4	
0.687	619	234	385	5.8	52	36.4	
0.688	620	234	386	5.9	52	36.4	
0.689	621	234	387	5.9	52	36.5	
0.690	622	234	388	5.9	52	36.5	
0.691	623	234	389	5.9	52	36.5	
0.692	624	234	390	5.9	52	36.5	
0.693	625	234	391	5.9	52	36.6	
0.694	626	234	391	5.9	52	36.6	
0.695	626	234	392	5.9	52	36.6	
0.696	627	234	393	5.9	52	36.6	
0.697	628	234	394	5.9	52	36.7	
0.698	629	234	395	5.9	52	36.7	
0.699	630	234	396	5.9	52	36.7	
0.700	631	234	397	5.9	52	36.7	
0.701	632	235	397	5.9	52	36.8	
0.702	633	235	398	5.9	52	36.8	
0.703	634	235	399	5.9	52	36.8	
0.704	635	235	400	5.9	52	36.8	
0.705	636	235	401	5.9	52	36.8	
0.706	636	235	402	5.9	52	36.9	
0.707	637	235	402	5.9	52	36.9	
0.708	638	235	403	5.9	52	36.9	
0.709	639	235	404	5.9	52	36.9	
0.710	640	235	405	5.9	52	37.0	
0.711	641	235	406	5.9	51	37.0	
0.712	642	235	407	5.9	51	37.0	
0.713	643	235	408	5.9	51	37.0	
0.714	644	235	408	5.9	51	37.1	
0.715	645	235	409	5.9	51	37.1	
0.716	645	235	410	5.9	51	37.1	
0.717	646	235	411	5.9	51	37.1	
0.718	647	235	412	5.9	51	37.2	
0.719	648	236	413	5.9	51	37.2	
0.720	649	235	414	5.9	51	37.2	
0.721	650	236	414	5.9	51	37.2	
0.722	651	236	415	5.9	51	37.2	
0.723	652	236	416	5.9	51	37.3	
0.724	653	236	417	5.9	51	37.3	
0.725	654	236	418	5.9	51	37.3	
0.726	655	236	419	5.9	51	37.3	
0.727	655	236	419	5.9	51	37.4	
0.728	656	236	420	5.9	51	37.4	
0.729	657	236	421	5.9	51	37.4	
0.730	658	236	422	5.9	51	37.4	
0.731	659	236	423	5.9	51	37.5	
0.732	660	236	424	5.9	51	37.5	
0.733	661	236	425	5.9	51	37.5	
0.734	662	236	425	5.9	51	37.5	
0.735	663	236	426	5.9	51	37.5	
0.736	664	236	427	5.9	51	37.6	
0.737	664	236	428	5.9	51	37.6	
0.738	665	237	429	5.9	51	37.6	
0.739	666	236	430	5.9	51	37.6	
0.740	667	237	431	6.0	51	37.7	
0.741	668	237	431	6.0	51	37.7	
0.742	669	237	432	6.0	51	37.7	
0.743	670	237	433	6.0	51	37.7	
0.744	671	237	434	6.0	51	37.8	
0.745	672	237	435	6.0	51	37.8	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.746	673	237	436	6.0	51	37.8	
0.747	673	237	437	6.0	51	37.8	
0.748	674	237	437	6.0	51	37.8	
0.749	675	237	438	6.0	51	37.9	
0.750	676	237	439	6.0	50	37.9	
0.751	677	237	440	6.0	51	37.9	
0.752	678	237	441	6.0	51	37.9	
0.753	679	237	442	6.0	51	38.0	
0.754	680	237	442	6.0	50	38.0	
0.755	681	237	443	6.0	50	38.0	
0.756	682	237	444	6.0	50	38.0	
0.757	682	237	445	6.0	50	38.0	
0.758	683	238	446	6.0	50	38.1	
0.759	684	238	447	6.0	50	38.1	
0.760	685	238	448	6.0	50	38.1	
0.761	686	238	448	6.0	50	38.1	
0.762	687	238	449	6.0	50	38.2	
0.763	688	238	450	6.0	50	38.2	
0.764	689	238	451	6.0	50	38.2	
0.765	690	238	452	6.0	50	38.2	
0.766	691	238	453	6.0	50	38.3	
0.767	692	238	454	6.0	50	38.3	
0.768	692	238	454	6.0	50	38.3	
0.769	693	238	455	6.0	50	38.3	
0.770	694	238	456	6.0	50	38.3	
0.771	695	238	457	6.0	50	38.4	
0.772	696	238	458	6.0	50	38.4	
0.773	697	238	459	6.0	50	38.4	
0.774	698	238	460	6.0	50	38.4	
0.775	699	238	460	6.0	50	38.5	
0.776	700	238	461	6.0	50	38.5	
0.777	701	238	462	6.0	50	38.5	
0.778	702	239	463	6.0	50	38.5	
0.779	702	239	464	6.0	50	38.5	
0.780	703	239	465	6.0	50	38.6	
0.781	704	239	465	6.0	50	38.6	
0.782	705	239	466	6.0	50	38.6	
0.783	706	239	467	6.0	50	38.6	
0.784	707	239	468	6.0	50	38.7	
0.785	708	239	469	6.0	50	38.7	
0.786	709	239	470	6.0	50	38.7	
0.787	710	239	471	6.0	50	38.7	
0.788	711	239	471	6.0	50	38.8	
0.789	711	239	472	6.0	50	38.8	
0.790	712	239	473	6.0	50	38.8	
0.791	713	239	474	6.0	50	38.8	
0.792	714	239	475	6.0	50	38.8	
0.793	715	239	476	6.0	50	38.9	
0.794	716	239	477	6.0	50	38.9	
0.795	717	239	477	6.1	50	38.9	
0.796	718	239	478	6.1	50	38.9	
0.797	719	240	479	6.1	50	39.0	
0.798	720	240	480	6.1	50	39.0	
0.799	720	240	481	6.1	49	39.0	
0.800	721	240	482	6.1	49	39.0	
0.801	722	240	483	6.1	50	39.0	
0.802	723	240	483	6.1	50	39.1	
0.803	724	240	484	6.1	50	39.1	
0.804	725	240	485	6.1	49	39.1	
0.805	726	240	486	6.1	49	39.1	
0.806	727	240	487	6.1	49	39.2	
0.807	728	240	488	6.1	49	39.2	

Time from Initiation (sec)	Forebody Travel Distance (ft)	TM Pack Travel Distance (ft)	Wire Deployed (ft)	Main Parachute Diameter (ft)	Velocity of Wire w/r/t Ground (fps)	Main Parachute Drag Area (ft^2)	Event
0.808	729	240	489	6.1	49	39.2	
0.809	730	240	489	6.1	49	39.2	
0.810	730	240	490	6.1	49	39.2	
0.811	731	240	491	6.1	49	39.3	
0.812	732	240	492	6.1	49	39.3	
0.813	733	240	493	6.1	49	39.3	
0.814	734	240	494	6.1	49	39.3	
0.815	735	240	494	6.1	49	39.4	
0.816	736	241	495	6.1	49	39.4	
0.817	737	241	496	6.1	49	39.4	
0.818	738	241	497	6.1	49	39.4	
0.819	739	241	498	6.1	49	39.4	
0.820	739	241	499	6.1	49	39.5	
0.821	740	241	500	6.1	49	39.5	
0.822	741	241	500	6.1	49	39.5	

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