

# STRUCTURAL CB CLOSURES FOR COLLECTIVE PROTECTION SHELTERS

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## ABSTRACT

No product or device either on the market or patented but not implemented, meets all the requirements for a CB closure. TPI has developed and prototyped a new design which complies with all of the CB seal requirements and which can be opened and closed from either side (inside/outside). In production, the new closure design will be a polyethylene extrusion matched to the M28 Liner material allowing easy thermal welding of the two. This development opens a huge potential for the closure as a substitute for zippers etc in other joint/closure applications including doors etc.

## BODY

### 1. Introduction

The level of protection offered by collective protection shelters is dependent upon the ability to create reliable hermetic seals at all interfaces between modular shelter units and interfaces such as airlocks, protective liners and ECUs. These seals must be CB and battlefield survivable in addition to withstanding mechanical loading due to shelter overpressures and real world field use. Methods and materials now used in this application are not optimal and in fact fail to meet some of the basic system criteria:

- resist 1-iwg overpressure with no detachment or leak
- resist expected field stresses (fabric loads, live loads, twisting, etc.)
- ease of use in all operational scenarios (cold/wet, night, masked/gloved, etc.)
- chemical resistant
- easy to clean
- easy to decontaminate
- no water leakage
- no air leakage
- easily attached to M28 liner material
- orientation independant
- low life cycle cost (\$1-2 per foot)
- high field utility (ruggedness, etc.)
- allows small radius curves (for corners of floor/wall etc.)

The current seal technologies are generally based on either the zip-track or zipper approach or a combination or variation of these themes – shown here integrated onto M28 liner sections (Figure 1). As general comments these approaches have small physical features and hence are difficult to keep clean (and hence functional), are hard to decontaminate, the zippers are expensive, the zip tracks are subject to

permanent deformation when rolled and subsequently leak, end points are difficult to seal, and the devices are difficult to bond to the M28 liner. This last point is an important one. The LDPE laminate liner is extremely tough to bond to and many of the current closure systems (since they were designed as generic industrial closures and not specifically for this application) are fabricated from incompatible materials. This has resulted in the need to use intermediate material between the closure device and the liner material complicating fabrication, adding to the cost and bulking out the stored volume of the liner system. A final point on zippers - the failure mode for zippers under excess local loading is an unacceptable one in this application (Figure 2). When the chain of the zipper fails under cross load, such as when a person falls against a closed zipper, it becomes impossible to reclose the chain with the slider (because the end of the slider nearest the failure is configured to open the chain not close it). This results in the slider jamming at the end of the failed (open) length and renders the closure unsealable and unusable.



Figure 1: Current M28 closure/seal approaches are a combination of zip-track and zippers.



Figure 2: Zipper failure mode is unacceptable for CB environments.

Based on these shortcomings SBC-COM contracted TPI to derive a better solution, compliant with all the above requirements and capable of being fielded in less than 2 years. The basic SOW was to complete a comprehensive technology review, derive an acceptable closure design and derive an acceptable methodology to allow direct attachment to the M28 liner.

## 2. Technology Review

The patent search offered the greatest potential for identifying a ‘new’ approach to solving the problem. TPI spent little effort in reviewing ‘conventional’ zip-track or zipper related patents. SBC-COM staffs are well aware of developments in these products. The total database searched during this effort exceeded 33,000,000 documents – the global patent database. This database was searched under an exhaustive variety of terms as single words and combinations. From this search 113 patents were subjected to a detailed review.

While each single example discussed next is different from the others they represent a ‘class’ of numerous similar designs. They are presented here to typify the state-of-the-art in closure design and to cover most of the approaches possible (albeit at a high level) to this problem. Many nuances and variations on each design is possible, the examples tabled cover the basic alternatives.

Many of the embodiments identified are linear ‘snap’ closures. This slide shows a variety of classic ‘Trident’ closures (Figure 3). They are all linear snap-lock fitting with multiple seal lines. These architectures are orientation independent, have no ‘ends’ to become leak paths and can be scaled to be sufficiently open to allow ease of cleaning. All provide multiple seal lines, can be heat sealed to a substrate for installation and are of sufficiently simple a profile and configuration as to be economical to produce in quantity. Arrowhead closure systems (Figure 4) actually form the basis for zip-loc and related designs. The basic arrowhead capture scheme can be supplemented with an inflatable section at the base of the female channel which, when inflated, will significantly increase the seal and structural capacity of the joint. This closure design could be implemented as either a hand closed or slider actioned system. Unlike some snap closures the simplicity of the design lends itself to fabrication in reasonably flexible rubber which can allow the system to be rolled up for storage. These linear closures can also be configured as a simpler embodiment that is basically an arrow-head system with a segmented female channel (Figure 5) to minimize section bend radius.

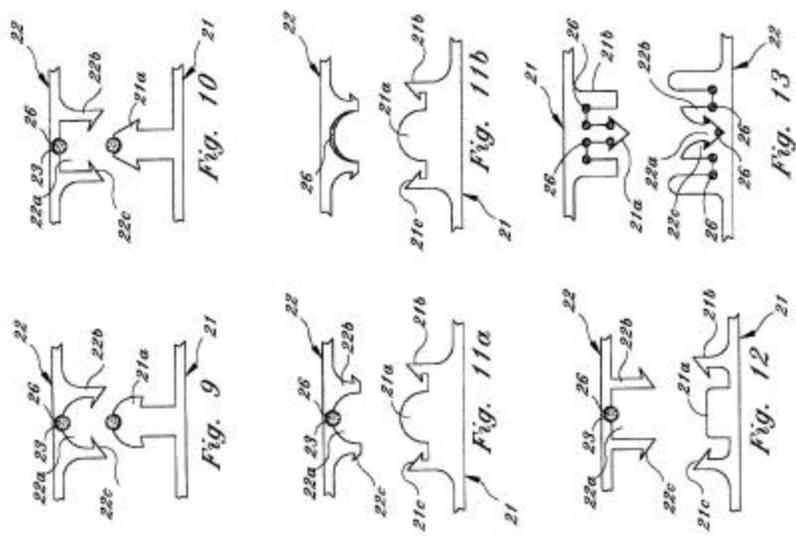


Figure 3: Trident closures form the basis for many ‘snap’ closures.

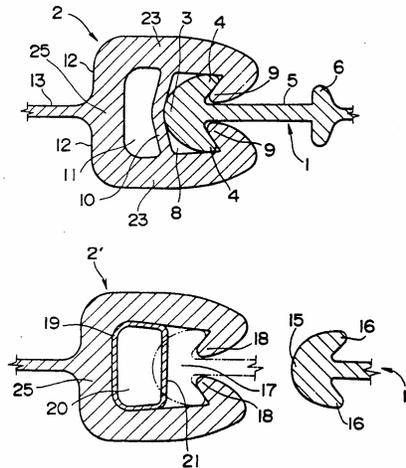


Figure 4: Arrowhead closures form the basis for Zip-Loc™ style seals.

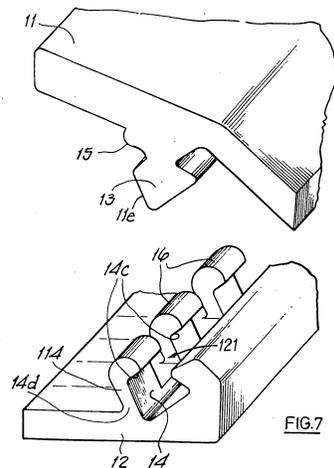


Figure 5: Modified snap closures can have minimal bend radii.

The real attraction of complex profile designs (Figure 6) is their ability to incorporate features to significantly enhance their tensile load capacity. The major drawback is the actual complexity of the profile and the requirement to ensure its cleanliness. Obviously such an approach will provide whatever number of seal lines is desired. Seal closure can be attained with either a slider action or manually.

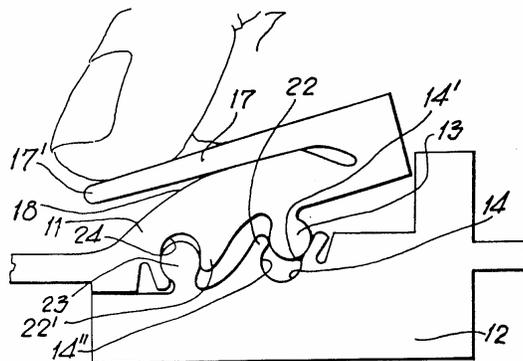


Figure 6: Complex profile closures can have very high tensile capacity.

Fres-Co USA has a new ‘Segmented Snap Closure’ that attaches to each half of a fabric joint (Figure 7). The halves are pressed together to lock the fabric between them and the system actually compresses the two layers of fabric against each other and a hard plastic channel at several places to provide multiple seal lines. The basic concept is a good one. It is extremely simple, can be scaled to ensure ease of use and cleaning, should be economical to produce, is completely reversible, has no ‘ends’ to break the seal and, at the correct scale, would be easy to close and open. However, it’s current implementation may not be applicable as is - the current configuration is designed for use with straight line seals and is not sufficiently flexible to be rolled and accept the curve radii that would be required. One solution to this deficiency would be to segment the seal into short lengths (as shown in a previous slide) and to install it in over lapping sections. When connected a continuous seal would be provided but when the halves are separated they could be folded along the segment lines for storage.

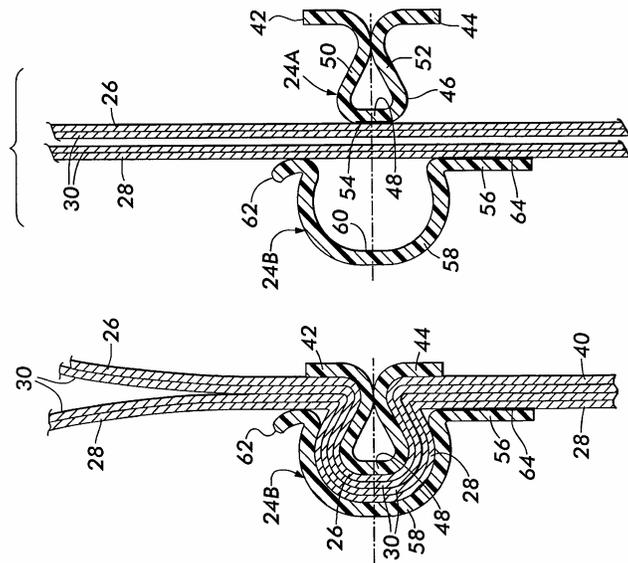


Figure 7: Some closures use the fabric itself as the sealing mechanism.

### 3. New Designs

Included in our review of applicable approaches and technologies were the ‘exotic’ candidates, namely:

- phase change gels & materials
- memory metals (nitinol etc.)
- active polymers (artificial muscles)

It very quickly became apparent that these technologies are still a long way from fieldable, economic maturity. They have very limited structural capacity and require complicated packaging schemes to allow their use in a ‘dirty’ field environment. They cannot come close to being an economic alternative.

TPI generated a family of closure designs based on more conventional approaches. These designs will not be covered in detail here but the summary list shown lists the prime reasons for their exclusion from further consideration:

- Magnetic Seals – difficult to get sufficient structural strength
- Interlocking Inflatable Seals – requires external support, not fail safe
- Vacuum Line Seal – requires external support, not fail safe
- Pressurize-To-Release Inflated/Mechanical Seal – requires external support
- Mechanical Closure (snaps, fasteners, bolt plates, etc.) – cumbersome, require secondary seal

In addition to the prime excluder shown here all the designs generated were subject to an evaluation against the system requirements detailed at the start of this presentation.

#### 4. The New TPI CB Closure

All efforts to date have indicated that one of the most likely useable designs will be a version of the ‘dart’ closure. Consequently, this design was selected as an initial starting point for the CB seal detailed development. The zero baseline design is shown in the slide (Figure 8).

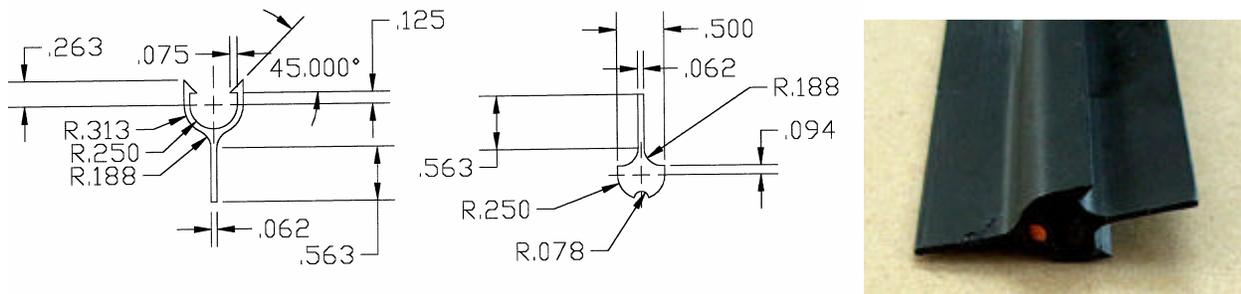


Figure 8: The ‘Dart’ seal was chosen as the zero baseline.

This design incorporates the following features:

- Positive locking of male/female halves
- Provision for a foam seal (the half circle cut out on the leading face of the male half) to maximize air and water tightness
- A physical size that is reasonably ‘hand friendly’ but small enough to minimize effects on storage and bend radii
- A tail for attachment to the liner material

Early prototypes of this design were fabricated in polyurethane (PU) because this material lends itself to easy fabrication in a vacuum casting process (low cost, rapid turnaround). Different resins were employed to produce prototypes with different stiffness and so varying ‘grip’ (male/female locking), bend radii etc. These characteristics are attained by varying material durometer (assuming a fixed profile). We have produced seal sections for test with durometers of Shore D 65, 50 and 45 and Shore A 80 – equivalent to a Shore D 35. At this time it appears that a profile with a durometer of around the D 45 offers the best combination of flexibility and mechanical connection strength.

These prototypes are currently produced in a small vacuum casting machine with a mold formed from a rapid prototyped (3D printing) positive. This positive is generated from a 3D model of the TPI design. The profiles shown are around 10-in long. This length is limited both by the capabilities of the 3D printing technology and the size of the casting machine (since we do not want to spend large amounts on tooling for a design which is not yet ‘cast in concrete’). This limitation was not too serious when we were trialling zero baseline sections for basic capability but as the design matured longer sections were required for test. Up to now the only option to achieve this capability was to invest in extrusion tooling. But again, because the profile was still being developed such an investment was not desirable. Under this impetus TPI has developed a technique to join several of the shorter sections into a homogeneous length. This is accomplished by splicing the pieces within the vacuum casting mold before the resin has fully cured. This results in an inter-melt of the old and new piece with the join section being close to homogeneous with the remainder of the length.

However PU can not be easily welded to the polyethylene (PE) coating of the M28 liner material. Once the design features and required physical properties (e.g. modulus, durometer, etc.) are finalized it will be extruded in a PE resin with matching properties to allow easy attachment to the liner (this will be discussed further later). One nice capability that production extrusion will give us is the ability to co-extrude the lower durometer (softer) seal. In the earlier version of the profile this seal was provided with a rubber element bonded to the profile material (Figure 9). The co-extrusion will actually be in Santoprene, a material used in a variety of FDA approved food and chemical environment sealing applications.



Figure 9: A low durometer rubber seal was used in early prototypes.

Structural capacity of the seal prototype was evaluated via imposing a dead load on the joined closure up to the failure (pull apart) point. For the TPI ‘Dart’ type closure this was achieved by mechanically clamping onto the flanges on the actual closures halves (Figure 10) and then applying a dead load to the joint. Several durometer variants of the closure were subjected to this testing with some impressive results (Table 1). As can be seen the higher durometer Dart seal offers the highest capacity by a considerable margin. The pull-apart test set-up was then reconfigured to accommodate single point loading of the profiles (Figure 11) via a nominally 0.25-in pin. The intent of the tests was to evaluate the profile holding strength against a worst case point load, such as a person pushing on it at a point. This slide (Table 2) summarizes these results and compares them to the original spread load results. The results are impressive but again will need to be repeated when the final profile configuration, material and properties are selected and prototyped.



Figure 10: Pull-apart testing was conducted on prototype designs.

Table 1: The simple Dart closure showed impressive strength.

Design	Mod Number	Durometer (Shore B)	Color	Length (in.)	Max Weight (lb.)	Lbs/In
TPI Dart	Unmodified	45	Brown	10	45	4.5
		65	Black	10	225	22.5
Fres-Co	Unmodified	n/a	Blue	10	15	1.5
TPI Dart	Mod-01	45	Brown	10	45	4.5
		65	Black	10	75	7.5
Fres-Co	Mod-01	n/a	Blue	10	15	1.5



Figure 11: Pull-apart strength was also tested in point load mode.

Table 2: Point and distributed load capacity was high.

Test Configuration	Profile (65 Durometer)	Result
Spread Load	Baseline	22.5-lb/in
Spread Load	Modified	7.5-lb/in
Point Load	Baseline	70-lb
Point Load	Modified	35-lb

Closure bend radius was evaluated by forcing the joint components and joined set around a series of circular guides. The minimum radius was considered to be attained when either the molding kinked or the closed joint came undone.

As seen in the slide (Figure 12), the female moldings tend to collapse closed when bent. This scenario will occur when the liner is rolled for storage. This is a material characteristic and will be addressed by material selection. When the minimum radius was exceeded with the closed joint they tended to ‘un-zip’ as shown in the next slide (Figure 13) – although this effect is somewhat a function of the test set-up: short lengths with free ends – and will not be as big an issue in long lengths with no ends.



Figure 12: Female moldings tend to collapse when folded.



Figure 13: At some minimal radius the profiles unzip.

One of the CB seal performance specifications is to resist 1-in WG of hydrostatic pressure. SBCCOM has provided TPI a hydrostatic test rig (Figure 14) to verify attainment of this requirement. For this testing the seal prototype/liner assembly is captured in a 5-in diameter ring clamp which forms a closed volume underneath the assembly. The test rig utilizes a small peristaltic pump to pressurize this volume with water and has a direct reading digital gauge for monitoring the applied pressure. Failure is indicated by a sudden drop in steady state pressure or leaking of the joint under increasing pressure. It should be noted that in all cases the failure did not involve leakage directly across the seal line (which would have resulted in a visible tell-tale of liquid within the top ring in the test set up). The failure mode was apparently via liquid entering the seal structure and then traveling along the seal and exiting once the joint was no longer intact outside the test ring assembly. All durometer seals resisted the hydrostatic pressure above 5-in WG (Table 3).

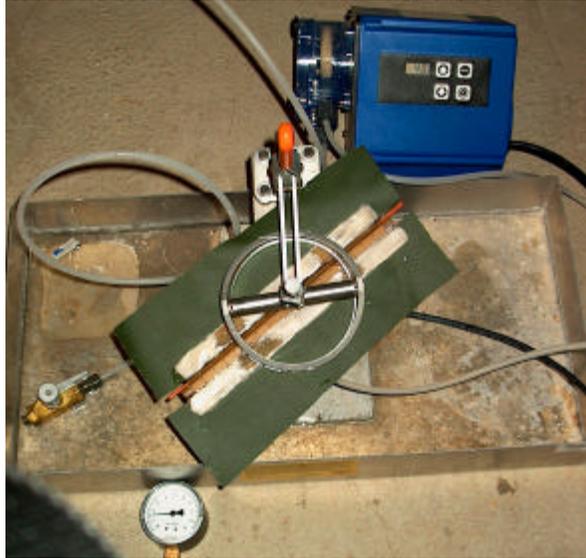


Figure 14: SBC-COM provided a hydrostatic test rig to evaluate designs.

Table 3: All prototypes easily exceeded the 1-in WG requirement.

Seal Design	Average Failure Pressure (in-WG)
ZIPlast	6-7
TPI 45 durometer Polyurethane	5-6
TPI 65 durometer Polyurethane	5-6

#### 5. CB Closure To M28 Liner Bonding

The prototype seal configurations discussed previously are fabricated from polyurethane (PU) resin. The M28 liner material is a polyethylene (PE) laminated material. Traditionally, PU fabric is radio frequency (RF) welded and PE is thermally welded (heat sealed). TPI has conducted a series of sealing test on the M28 liner material provided by SBCCOM and on the PU seal prototypes. The goal of this testing is to identify a method to allow the attachment of the liner material to the prototype seals in an expeditious manner while retaining the designed flexibility of the seal. The optimum approach is a welded joint – quick, flexible, high structural capacity. However, historically, attaining this goal has been problematic with the M28 seals and in the current configuration an intermediate material is necessary between the liner and the sealing structure. The goal is to delete this intermediate material. This implies that the seal structure and liner material be of a like class, that is PE. Therefore TPI is completing a search for materials for the seal with two critical properties:

- physicals (modulus, flexibility, etc.) which emulate the performance of the polyurethane prototypes, and
- adhesion or welding compatibility with the polyethylene liner to eliminate the present need of an intermediate material between the M28 liner and the sealing structure.

Because the M28 material is made of LDPE (low density polyethylene) the first area of research was in the Polyethylene family of resins. The resins reviewed are as follows:

- Ethylene-Ethyl Acrylate (EEA) - EEA is among the toughest and most flexible of the polyolefin's. This resin is frequently used to blend with LDPE and LLDEPE to produce intermediate modulus products. This resin can be profile extruded with standard equipment.

- The material exhibits higher resistance to stress cracking, impact and flexural fatigue. This resin is able to be heat sealed to LDPE with good bonding strength.
- Ethylene Acid Copolymer (EAC) - EAC, similar to LDPE, is a flexible thermoplastic having water and chemical resistance and barrier properties similar to LDPE. This resin can be processed on standard extrusion equipment made of corrosion resistant material or protected with chrome or nickel. This material can also be used to modify the LDPE for enhanced mechanical properties. This resin is able to be heat sealed to LDPE with good bonding strength.
  - Ethylene-Methyl Acrylate (EMA) - EMA is one of the most thermally stable of the alpha olefins. This material can be profile extruded with standard equipment, and be fiber/glass filled to 50% with out loss of elastomeric characteristics and is compatible to all polyolefin resins. This material can also be blended with LDPE to improve impact strength and toughness, increase heat seal response and promote adhesion. This resin is able to be heat sealed to LDPE with good bonding strength.
  - Ethylene-propylene-diene monomer (EPDM) - EPDM is a flexible material compounded with propylene to create a thermoplastic elastomer of varying densities. They can be profile extruded on conventional equipment, and are heat sealable to LDPE.
  - Flexomers (ULDPE and VLDPE) - These are copolymers with densities below 0.915 and offer flexibility that was only previously available with lower strength materials. They can be compounded with other materials of the PE family to obtain various properties that are required. This resin is able to be heat sealed to LDPE with good bonding strength. It exhibits good environmental resistance and resists flexible stress cracking.

Coupons of some of these polymers have been tested for weldability to the liner material (Figure 15). In early cases initial failure occurred at 25-lb load (6-lb/in) when the welded area of the joint peeled off the polyethylene substrate cleanly. This indicates an insufficient application of heat and/or pressure to the weld during joining. These welds were remade with increased pressure applied, but the duration held constant. Consequently the universal failure mode was the M28 liner tearing off at the weld line. This failure occurred at a load of between 5 and 8-lb/in. This is half of the specified tongue tear for the liner material (15-lb/in) and indicates that the liner material was over cooked in the area of the weld.



Figure 15: Bonding of the closure material to the M28 liner is also under test.

These results are encouraging. It appears that with the proper equipment and a consistent weld process the M28 liner can be bonded with an acceptable joint being produced. This optimism is tempered with the proviso that when additives are incorporated into the resin to match required physicals the weldability could be significantly effected.

With all the difficulty that historically occurred with welding to the M28 material, we have been reviewing the fall back option of adhesively bonding a new closure to the fabric. Fortunately, the polyethylene family also offers a wide range of substrates that can be joined with common adhesives, such as:

- Epoxies
- Polyesters
- nitrile phenolics
- Epoxy phenolics
- polyurethane's and
- hot melts.
- and primers may be used to improve strength.

However this family is not as easily bonded as some other plastics, mainly because of poor wetting characteristics. Since surface wetting is the prime requisite for obtaining a good adhesive joint, some steps must be taken to increase wetting or increase surface free energy. Wetting the surface, although essential, is not enough to produce satisfactory bonds. The weak boundary layer must be removed, and success is also dependent on the viscoelastic properties of the adhesive. The three most highly recommended methods for preparing the surface are shown in this slide (Figure 16). As one can see, the use of adhesives to join the Seal Profile to the M28 film is quite involved and in all likelihood is not a workable solution. Therefore the need to develop a 'weldable' seal of a compatible material method remains of paramount importance regardless of the final profile.

- Method A
  - Degrease with acetone, MEK, or xylene
  - Immerse in the following solution maintained at 155 to 165 deg.F for 5 to 10 minutes:
    - Sodium dichromate.....15 parts by weight
    - Concentrated sulfuric acid.....250 parts by weight
    - Distilled water.....25 parts by weight
  - Rinse with distilled water and dry at 110 to 120 deg. F for 15 to 30 minutes.
  - Apply adhesive and or primer as soon as possible
- Method B
  - Immerse at 165 to 765 deg.F for 5 to 8 minutes In the following solution:
    - Concentrated sulfuric acid.....150 parts by weight
    - Potassium dichromate.....8 parts by weight
    - Distilled water.....10 parts by weight
  - Rinse with distilled water and dry as quickly as possible.
  - Apply adhesive and or prime as soon as possible.
- Method C
 

In the event that acid or oxidizing flame treatment is impractical or geometry is complicated then a Gas-plasma treatment has proved to be an effective means of surface preparation for adhesive bonding. Subjecting the surface to an electrically activated inert gas and utilizing a glow-discharge tube accomplish this treatment.

Figure 16: Adhesively bonding the materials is very tedious.

## 6. The CB Closure System

One of the major reservations with the current CB 'Dart' closure profile is the difficulty that will occur in opening and closing the seal when it is fixed to long lengths of liner and so access to the seal line is only realistically available from one side. This is not an issue with short lengths of prototype closures but will be a real issue in full scale implementation onto the M28 liner. One of the real attractions of zippers is that they can be operated from either side, and with two sliders can be operated from either end. With these issues in mind TPI has been developing a modified dart closure that will allow functioning from either side (inside or outside the closed volume) (Figure 17). This is a concept for a hermaphroditic, dual dart closure system incorporating a two way slider. The profile shown is basically two of the previous simple profiles back-to-back. This design is opened and closed from either side by the action of the slider (similar to a zipper or better yet think of a zip lock baggy seal scaled up by a factor of 50 and fitted with a slider on the outside and inside). The slider is captive to the profile (it engages in the circular track at the corner of the flange as identified in the figure). As the slider moves along the profile it pulls the two halves together and the leverage on the profile forces the seal half on the other side of the fabric panel to close as well. Initial engagement of the slider for the first closure point would be via a short cut out in the outer face of the female half of the seal profile.

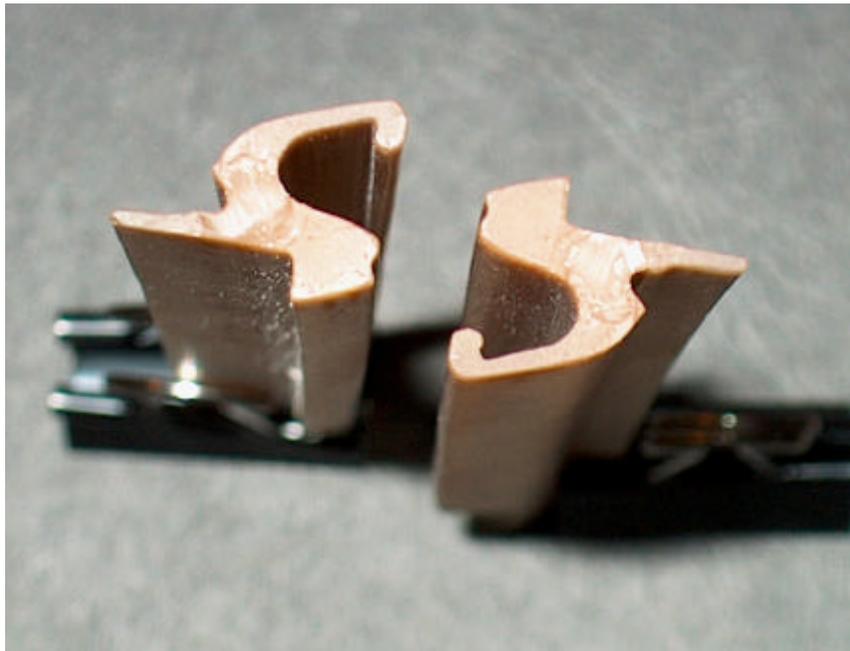


Figure 17: A hermaphroditic double dart will allow operation from both sides.

Shown in this slide (Figure 18) are two separate devices, one to 'zip' or close the seal and one to 'unzip' or open the seal. These devices are loaded onto the seal via a cut out on both halves of the profile (the end of which can be seen at the right hand end of the profile in the Figure). The next step in the development was the integration of the two devices into one combined unit (much like a zipper slider). This device has been prototyped (Figures 19 a & b) as a small (3-in long) item with a pivoting arm used to bring the unzip arm into contact with the profile when needed. This device is also loaded onto the profile via a cut out in the seal profile as seen previously. This device is currently under test. It has demonstrated the ability to join sections of fabric as in an M28 section to section connection with closing and opening from both sides and is now being integrated into a larger panel of fabric to allow its evaluation as a personnel door. Unfortunately those tests were not complete in time for this conference.

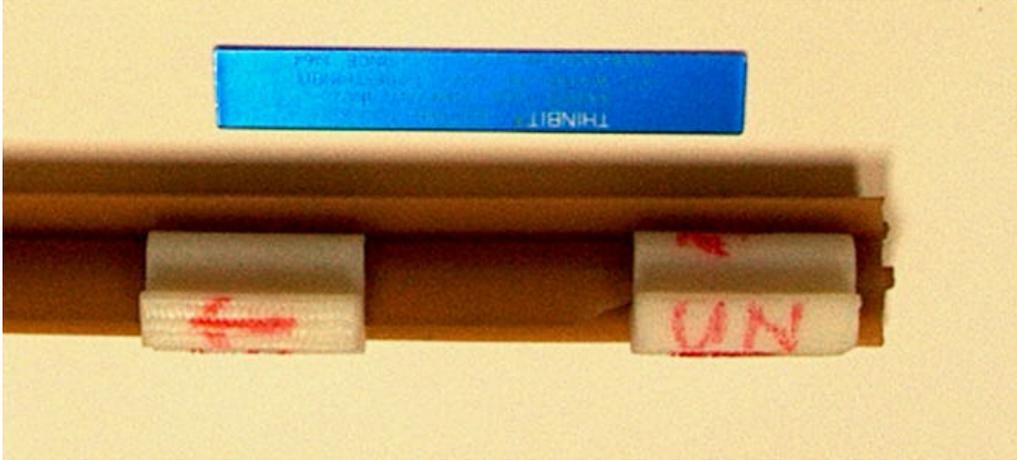
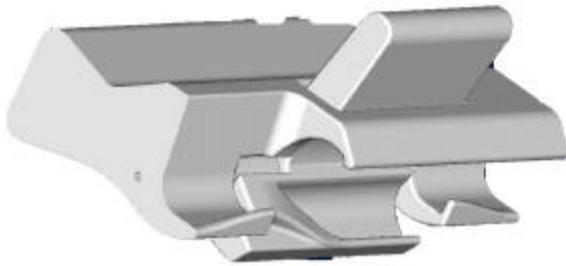
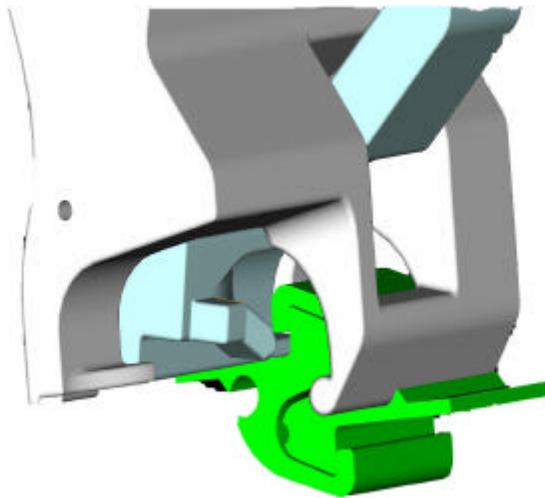
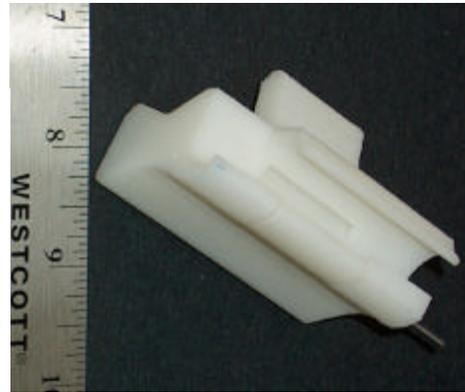


Figure 18: Early sliders were discrete ‘zip’ and ‘un-zip’ devices.



(a)



(b)

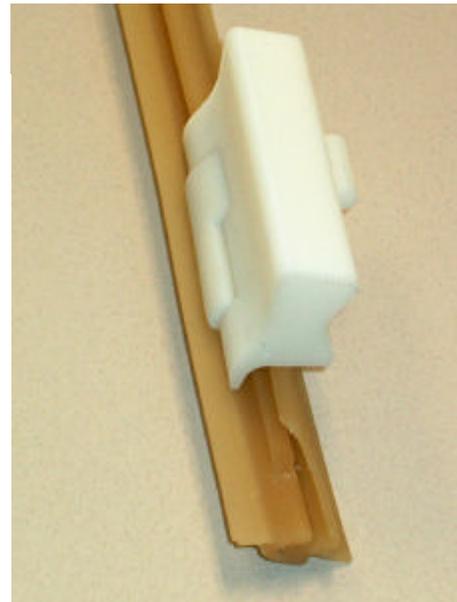


Figure 19: Two generations of an integrated slider that performs both ‘zip’ and ‘un-zip’ functions.

## CONCLUSIONS

If this concept can be properly implemented in a design that avoids the pitfalls of zippers and zip-track (cost, difficult to clean, difficulty of attachment to M28 Liner) but which attains all the stated goals of this program (tensile strength, hydrostatic resistance etc.) it will represent a major advance in closure systems. A closure with these capabilities would find broad application. With its open, easy to clean and decontaminate profile, low cost (as an extrusion), good inherent flexibility and strength it could find wide utility in both military and commercial applications. It will be suitable for all shelter and liner closures not just to seal M28 joints, but as doors and all other openings requiring frequent opening and closing from both inside and outside of the sealed liner. It has the potential to replace zippers, zip-track, Becket lacing and other closure and panel joining methodologies across the whole range of military and commercial tentage.