NHU-T-06-007

Sea Grant
New Hampshire

The Behavior and Holding Strength of Darts used to Attach Pop-up Satellite Tags, Through the use of Pull-Out Testing

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April 21, 2006

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Acknowledgments

We would like to thank Ken Baldwin and Nuno Fragoso for their guidance and support as our project advisors. A special thank you to Professor Baldwin for offering us his vast knowledge in ocean engineering and for his creativity, enthusiasm and constant encouragement kept us going through our year long journey. Nuno Fragoso for keeping us on top of our tasks and never settling for anything but the best out of us and for allowing us to use his knowledge of large pelagic fish tagging for our research. Paul Lavoie for allowing us to use the Ocean Engineering Machine shop and for his helpful guidance and supervision while in the shop. Andy McCloud our resident LabView expert who supplied us with the electrical parts needed to run the computer program. Adam also offered us his electrical expertise and the electrical components need for the apparatus. Thank you to Sheldon Parent for his patience with us while we used the J-Lab in Kingsbury to run initial tests and ensure proper set up of the apparatus and its components. Great appreciation to Molly Lutcavage and the Large Pelagics Department for giving us the opportunity to research the importance of PSATs on large pelagic fish. Thank you to Walt Johnson from Gelita North America for his help obtaining Ballistics Gelatin and for providing us with the necessary information to make the Gelatin properly. Thank you to RIFFE International, INC for supplying us with the tools needed to make the Musyl flopper dart. An overall thank you to everyone in the Ocean Engineering Building for allowing us to use office space needed to run our pull out tests.

This work is a result of research sponsored in part, by the National Sea Grant College Program, NOAA, Department of Commerce, under grant #NA16RG1035 through the New Hampshire Sea Grant College Program.

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Abstract

Large pelagic fish are an area of mystery; through the use of Pop-up Satellite Archival Tags (PSATs) more information can be obtained. PSATs are used for large pelagic fish data acquisition and connect information to a satellite data base. Failure by the dart anchors used to hold PSATs underneath the flesh of large pelagic fish has resulted in the loss of data and unreturned PSATs from the wild. Testing the holding force needed to anchor a PSAT into a large pelagic fish provides useful information about the behavior of the darts used and why failure is occurring. Four darts commonly used for tagging large pelagic fish were tested during this experiment, the eight prong umbrella dart, two and four prong billfish darts, and the Mike Musyl flopper dart design. The umbrella darts and the two and four prong darts were tested ten different times and the Musyl dart was tested three different times. A custom made Pull Out Apparatus (POA) applied a constant speed to each of the darts pulled out of the ballistics gelatin used as a standard medium made to simulate pelagic fish flesh. The four groups of darts all exhibited similar behaviors within the dart type. Similar pull out forces, physical damages on the dart and deformation on the gel were seen within the four dart types. A comparison between the four different dart types resulted in the PIMA 4 pronged dart having a stronger holding force than the PIMA 2 pronged dart, and the 8 pronged umbrella dart exhibited a stronger holding force over time than the PIMA darts. The PIMA darts had the strongest base holding force compared to the other two darts. This experiment creates a standard and repeatable testing mechanism that can be used to make improvements on future darts manufactured for PSATs.

Introduction

Pop-up satellite archive tags (PSAT) are used to track the migration and diving behavior of large pelagic fish and marine turtles (Microwave Telemetry Inc.). Data collected from these tags are used to understand the physiological ecology of various large pelagic species (Lutcavage et al. 1999; Block et al. 2001; Seitz et al. 2002; Domeier et al. 2005; Hoolihan. 2005; Wilson et al. 2005). Data archived in the PSATs provide useful information for conservation and management of the highly migratory marine organism.

Currently, PSATs record light level, depth, and temperature while the organism moves through the water column (Wildlife Computers). Light levels are used to estimate the geo-location, providing projected migration pathways. Temperature is used to correct geo-location estimates and also to describe the fish's thermal preferences. Vertical diving behavior can be elucidated from the pressure data recorded (Grusha and Patterson, 2005). PSATs are equipped with a fail-safe mechanism which detaches the tag from the animal after 4 days at a constant depth (Wilson et al. 2005) or when the organism dives below 1800m (Wildlife Computers). Once these tags detach from the fish, either after the programmed date or due to pre-release, they float to the surface and began transmitting data to the Advanced Research and Global Observation Satellite (ARGOS). Data is transferred to the researcher via the tag manufacturer after processing the Argos stream. An important aspect of the PSAT is that it provides fishery independent data and allows researchers a timeframe for when to expect results (Block et al. 1998).

A major problem that researchers face when using PSATs is poor retention of the tags (Holland et al. 2003). The PSATs are most useful when they remain attached to the animal for the desired length of time. In a tagging study performed by Wilson and colleagues (2005) three of 68 tags remained attached until their pre-programmed release date. Premature release problems prevent data acquisition of year long movements and annual migration patterns (Holland et al. 2003). Possible reasons leading to the pre-release of the PSAT include: tissue rejection of the dart and/or the dart's materials, failure of tissue holding dart, damage to the tuna's skin or muscle due to movement of the tag and tether, drag force on tag being too great for the fish's size, and movement of dart back through the cavity it created (Molly Lutcavage, personal communication). Grusha and Patterson (2005) determined that total force; both lift and drag, acting on the tag may contribute to premature release of the PSAT. External forces which are also considered to play a role in premature shedding of the PSAT include: inaccurate placement of tag, predation by other fish, failsafe release activated, software malfunctions, or failure of attachment materials (Molly Lutcavage, personal comm.). Ideal placement of the dart head is directly behind the second dorsal fin so that the dart is able to catch on the pterygiophores (Stokesbury et al. 2004). No published data exists to support any one of these possible mechanisms of failure. As important as these PSATs are to the science community there has been little work done on determining possibilities of failure or ways to mitigate these faults.

This study examined the holding strength of existing dart anchors. A similar study was conducted by Christopher Jones (2003) on Red Snapper *(Lutjanus campechanus)* and Red Drum (*Sciaenops ocellatus*). Jones (2003) tested the level of force needed to pull out two different darts, a single barbed and a double barbed dart, in each fish species. A hand held digital force gauge measured the force used for each pull out test. Results suggested that the double barbed dart held more force over time than the single barb in both fish. The mean pull out force for each dart over time was much more variable in the red snapper. However, there were several problems with his testing methods that included: the monofilament breaking during the pull out tests and false readings using the digital force testing equipment, leading to large statistical errors about his means. Another large problem Jones encountered in his study was pre-mature shedding of the darts and mortality of his testing subjects, both red drum and red snapper. Jones placed 80 tags in each species, only 58 darts contributed to the data for red drum and only 52 for the red snapper as a result of shedding and mortality.

Creating a repeatable experimental approach to test the pull out force of darts used to anchor the PSAT was the main goal for this study. Four darts currently used to anchor PSATs were tested: eight prong umbrella dart (PIER – Pfleger Institute of Environmental Research, Oceanside, CA) two and four prong billfish darts (PIMA – plastic head intra-muscular tags, Southeast Fisheries Science Center, Miami, FL) and the Mike Musyl flopper dart design. Ballistic gelatin was used as a standard testing medium and pull out test were performed by a custom built computer controlled apparatus. A Finite Elemental Analysis (FEA) was performed on the 2 prong PIMA dart. FEA is the process of separating an object into multiple elements and analyzing each element individually then combing the analysis to make a complete model of the object. FEA was used to create a model of the 2 prong PIMA dart and determine the areas of stress and deformation. This analysis allowed for an easy manipulation of the boundary condition of the dart allowing for the finding of the maximum force than can be applied without losing holding power. This experimental design as well as information gained from the FEA should provide more significant results compared to the Jones' thesis due to the repeatability and standardization of the test design.

Methods and Materials

The pull out force of each of the darts was measured using a pull out apparatus (POA) constructed specifically for this project. The pull out apparatus was connected to a load cell that converted the force of the POA (Figure 1) to a voltage value. The load cell was connected to the signal generator and allowed for a larger range of voltage (0-7V). From the signal generator a data acquisition board was connected to the computer allowing the computer to read the voltage processed by the POA. The computer program LabView was run on a manufacturer computer specially designed for engineering experiments. The LabView program reads data at a 100 hertz sampling rate and creates a data point for every hundredth of a second. The data obtained from LabView was stored to an excel file and graphs were created comparing Force (N) vs. Time (S).

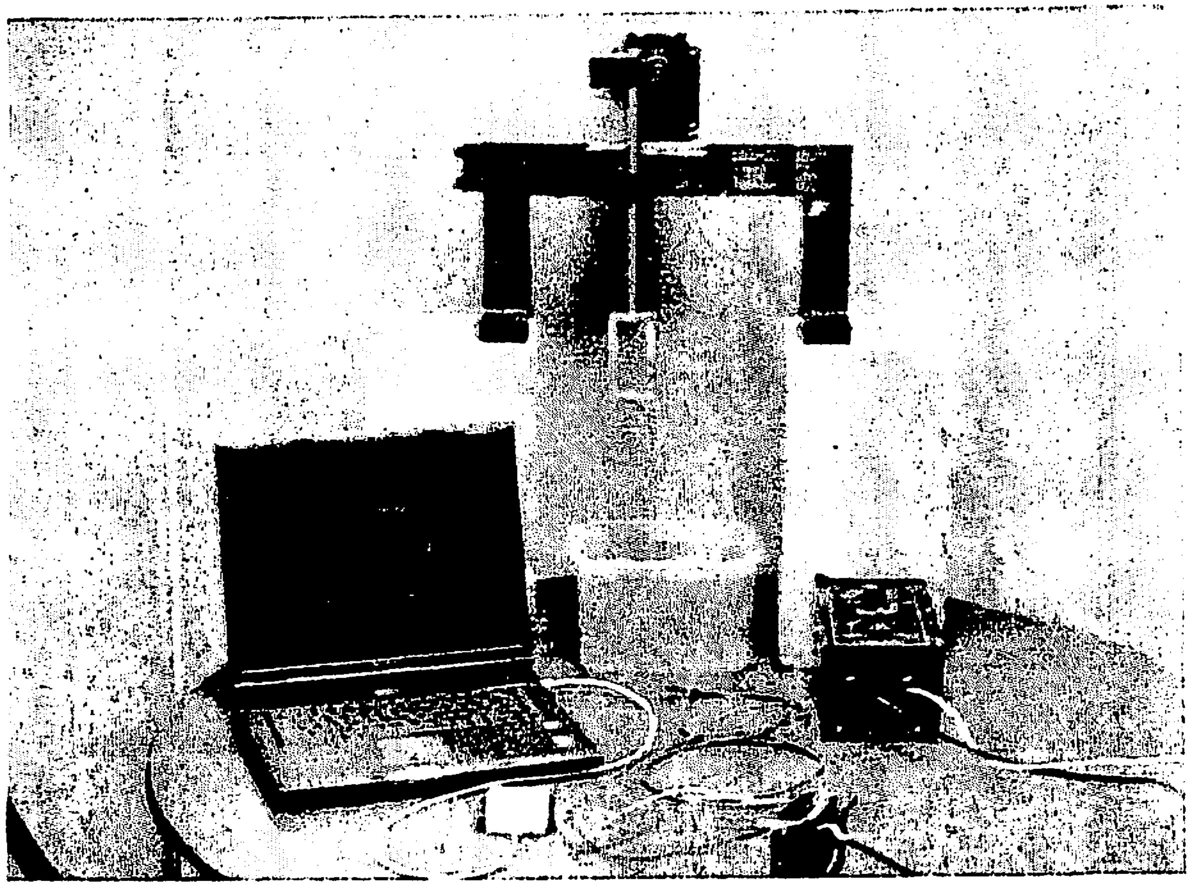

Figure 1. Pull out apparatus (POA).

The two and four pronged PIMA darts were obtained from Southeast Fisheries Science Center, Miami, Fl. (Figures 2 and 3), PIER umbrella darts were obtained from the Pfleger Institute of Environmental Research, Oceanside, CA (Figure 4) and Mike Musyl flopper darts (Figure 5) were designed by hand. The flopper darts were constructed by shaving both barbs off of the two pronged PIMA dart and drilling holes on either side of the dart, leaving one hole closer to the none barbed end than the other hold in order to fit both of the metal harpoon barbs. Metal harpoon barbs used for the flopper dart were obtained from RIFFE international, INC, San Clemente, CA. The metal barbs had a length of 2 3/16" and one barb was attached to either side of the dart using small rivets (Figure 5).

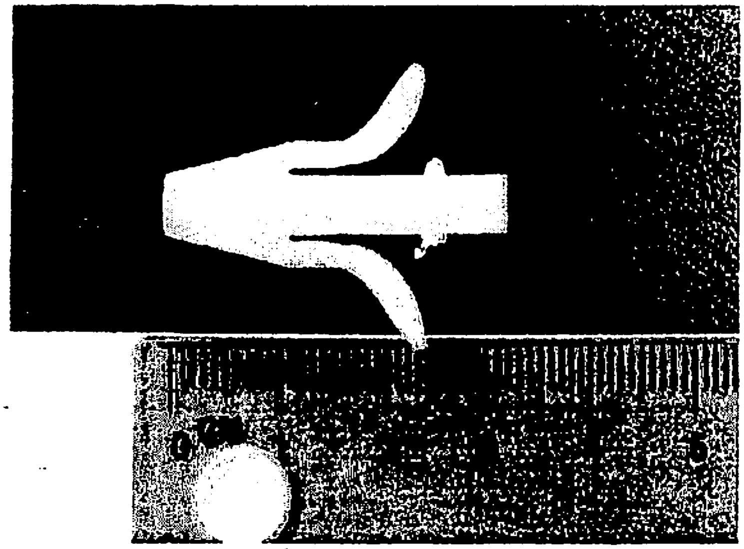

Figure 2. Two pronged billfish PIMA dart.

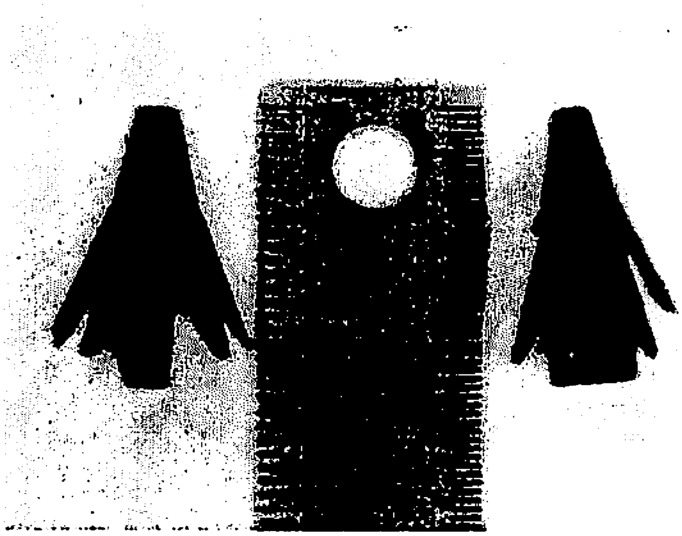

Figure 3. Eight pronged umbrella dart (PIER).

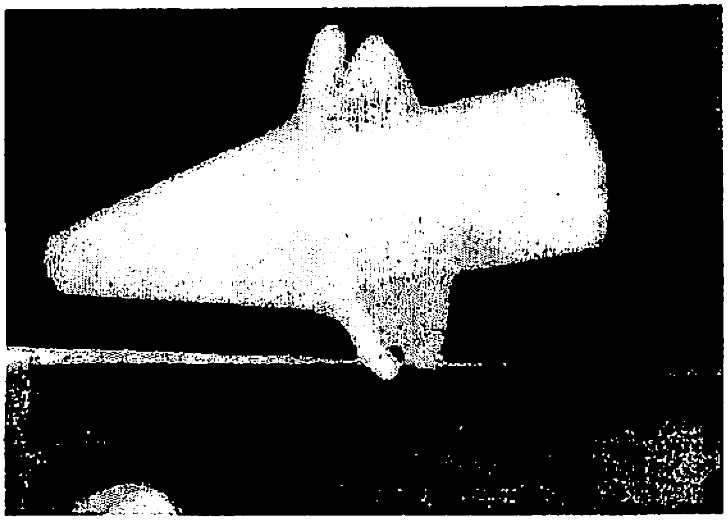

Figure 4. Four pronged billfish PIMA dart.

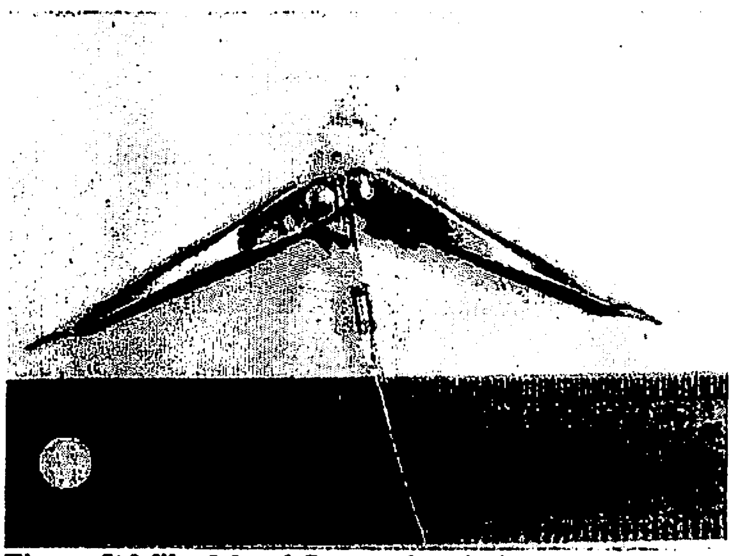

Figure 5. Mike Musyl flopper dart design.

The ballistics gelatin medium was obtained from Gelato North America and shipped in powered form. Construction of the gel was done using water, a cold source, and a heat source. For our experiment we used a 20% solution of the ballistics gelatin. In order to make a 20% solution (Ballistics Gelatin Protocol, Appendix A) 500g of ballistics gelatin added to 2.5 L of water to make a 3 L final volume of solution. 2.5 L of water was cooled to 4°C and the 500g of ballistics power was added slowly to the water to insure that no clumping occurred. After all of the powder was fully dissolved into the water the mixture was stored in a 4°C refrigerator for 2 hours. The cooled mixture was placed in a large cooking pot and heated on the stove until it reached a temperature of 37.7° C. Once fully heated the mixture was poured into a 29.21 cm x 13.97 cm x 21.59 cm mold, a 34.29cm x 17.78cm x 24.13 cm mold and smaller 20.32cm x 16.51cm x 13.97cm molds and left in a 4°C refrigerator for 22 hours to harden.

The two pronged PIMA, four pronged PIMA and 8 pronged PIER umbrella darts were all tested 10 times in the smaller (20.32cm x 16.51cm x 13.97cm) molds. Two pull out tests using two randomly selected darts were performed in each container. Three of the Mike Musyl flopper darts were tested using the two larger containers, two of the flopper darts were placed in the larger container (34.29cm x 17.78cm x 24.13 cm) and one dart was tested in the 29.21 cm x 13.97 cm x 21.59 containers.

All of the darts were attached to the POA using monofilament Jinki 250lb and sleeves were used to secure the dart to the POA. An applicator needle (PIER) used to attach PSAT darts in the field was used to insert the darts into the ballistics gelatin. The dart was inserted into the gel until it reached the bottom of the container (average 9.35cm). Once the dart was inserted into the gel the POA was turned on and run at a constant speed (30%rpm). During the actual pull out tests data was recorded on the computer using LabView and files were saved on excel. All graphs and figures were made using Microsoft Excel©.

Results

The umbrella darts (Figure 6) start off with increasing force at a constant slope. The first initial increase in the slope from 0-3 sec models the initial anchoring of the dart barbs to the medium. After the dart had been anchored into the medium for ~4 sec there was a small jump in the force (Lb) exhibiting the initial resistance of the dart to the force of the POA. During the 5-15 sec interval the increase in slope was created by the barb flexing and resisting against the medium and the force. The peak of the graph ~10-20 sec is the point at which the dart has begun exiting the medium and failing. After reaching a maximum force the dart begins to re-anchor into the medium, the downward slopes (~20-45 sec) model this behavior. Dart #s 1(test #1), 24 (test #8), and 29 (test #10) broke during pull out testing.

Table 1. Measurements and specific physical characteristics of each dart type.

Measured in Micrometers	Pima 2	Pima 4	Umbrella	Flopper
Length of dart (in)	1.232	1.297	1.236	3.25
Length from tip to barb point (in)	0.93	1.071	1.072	3.25
# of barbs	2	4	8	2
Surface area per barb (in^2)	0.144	0.166	0.052	0.656
Entrance area (in^2)	0.357	0.776	0.268	0.625
Eye holes distance from center (in)	0.091	0.086	0.104	0.115
Eye holes distance from edge (in)	0.082	0.095	0.075	0.092
Eye holes distance from end (in)	0.269	0.352	0.11	0.437
# of darts	27	30	61	10

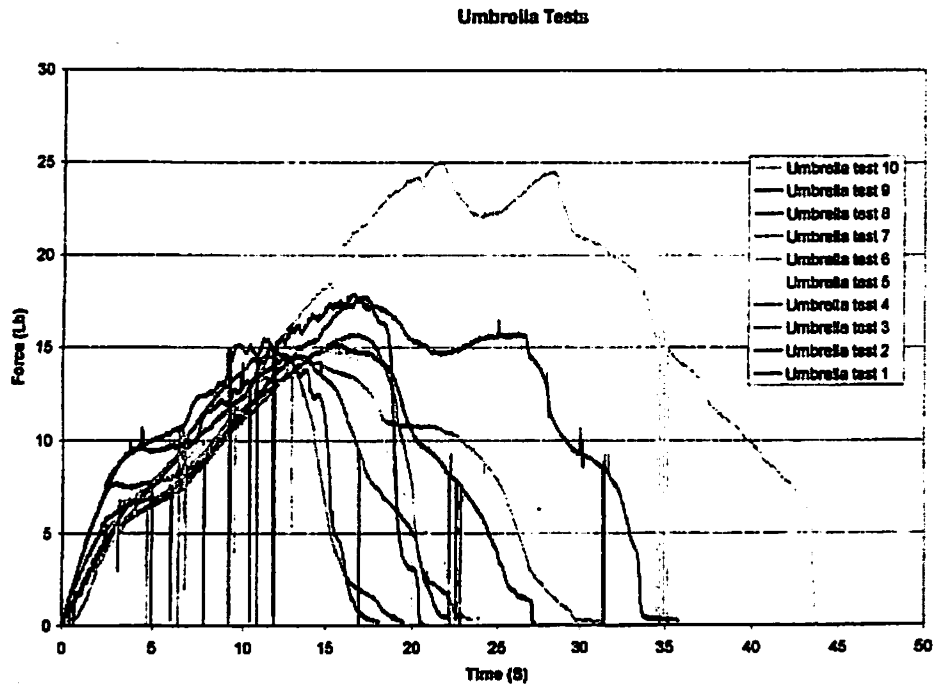

Figure 6. The results for each of the ten trials of Force (Lb) vs. Time (s) for each test of the eight prong umbrella dart (PIER).

The two pronged PIMA darts (Figure 7) exhibit an increasing force at a constant slope. The positive increase in the slope (~0-10 sec) models the anchoring of the dart to the gel medium and the approach of a maximum threshold on the gel. Tests 1, 2, and 7 give examples of the material not providing enough resistance to the dart. In all other tests run (3, 4, 5, 6, 8, 9, and 10) the slope begins to slowly decrease (~15-35 sec) until the force reaches zero.

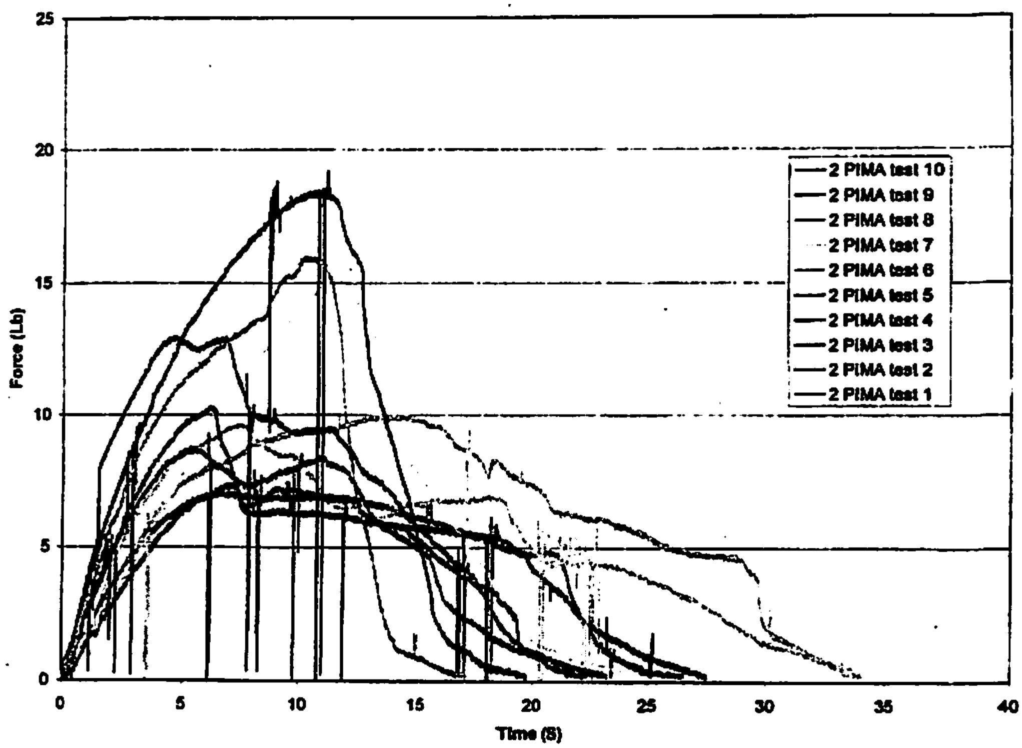

Figure 7. The results in Force (Lb) versus Time (s) for each of the ten 2 prong PIMA pull out tests.

The 4 pronged PIMA (Figure 8) had the strongest initial anchoring in the gel. When pulled out the anchor never re-caught in the gel and little resistance was seen. The constant positive slope (~0-5 sec) until a maximum force was reached (~5-10 sec) shows the darts initial anchoring was the strongest.

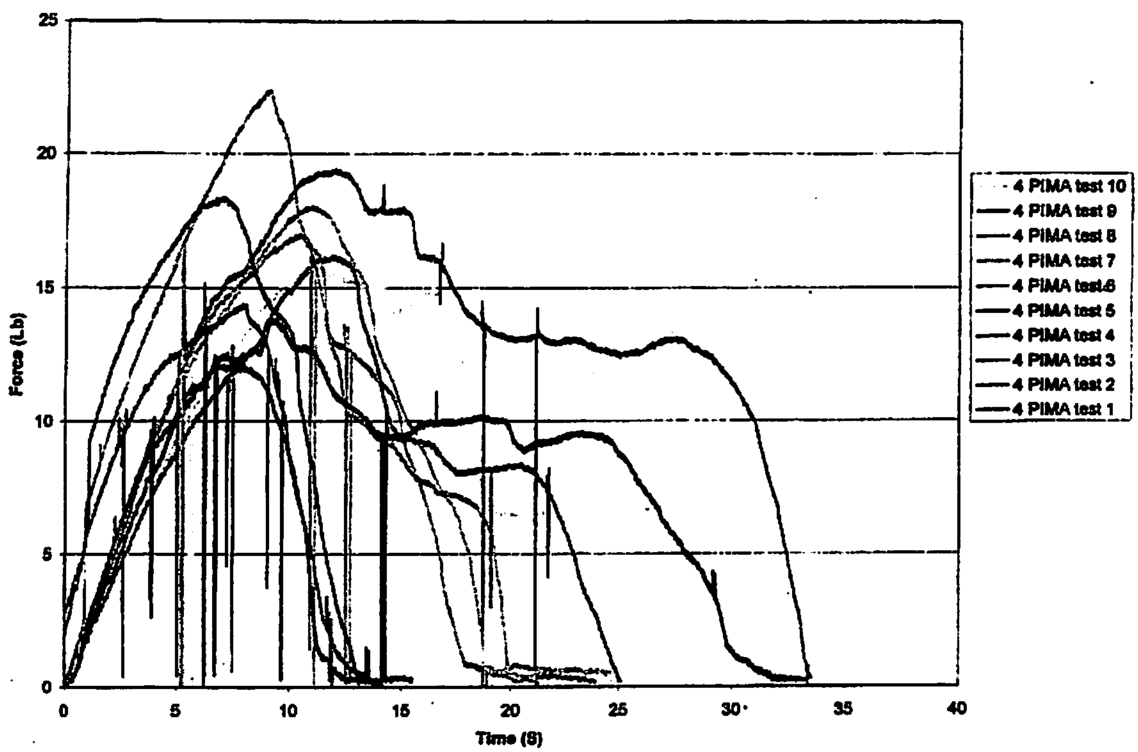

Figure 8. Force (Lb) versus Time (s) including each of the ten trials conducted using the 4 prong PIMA dart.

The Mike Musyl Flopper Dart (Figure 10) expressed a very high initial holding force that stayed constant from 0- 20 second. The over all holding strength of the Flopper darts exhibited the greatest holding force in the gel.

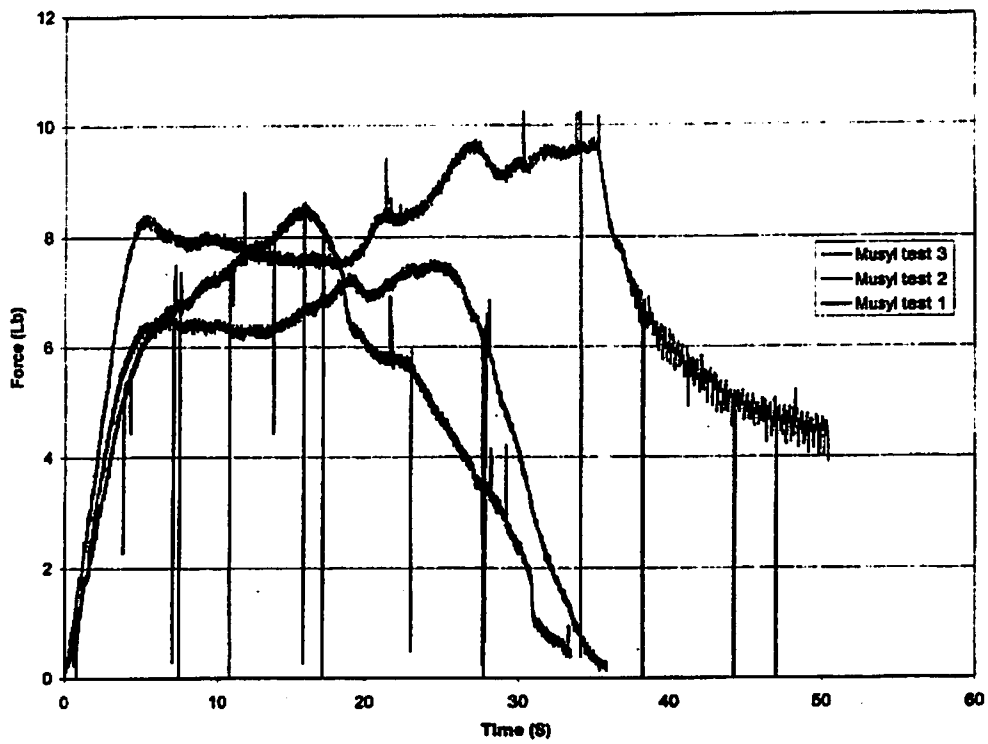

Figure 10. Force (lbs) versus Time (s) for each of the three trials ran using the Mike Musyl flopper dart design.

The only way to ensure the darts are being pulled out of the same medium is too due a pull out of each dart in the same container allow for best comparison of darts. In container #8 two PIMA darts and an umbrella dart were pulled out. In Figure 11 the darts all start out with the same force slope. The umbrella dart changes force slope do to the barbs flexing out and cutting the gel. The PIMA darts behave very similarly but the holding strength of the 4 PIMA is greater than 2 PIMA; which means the adding of two barbs increased the holding strength without changing the behavior of the dart. The maximum holding strength for the 4 PIMA and umbrella dart are approximately the same. However the 4 PIMA dart hits the maximum holding strength sooner then the umbrella dart. The 4 PIMA hits maximum strength first do to the first anchoring of the dart being the strongest; where as the umbrella darts holding strength increases as the barbs flex out.

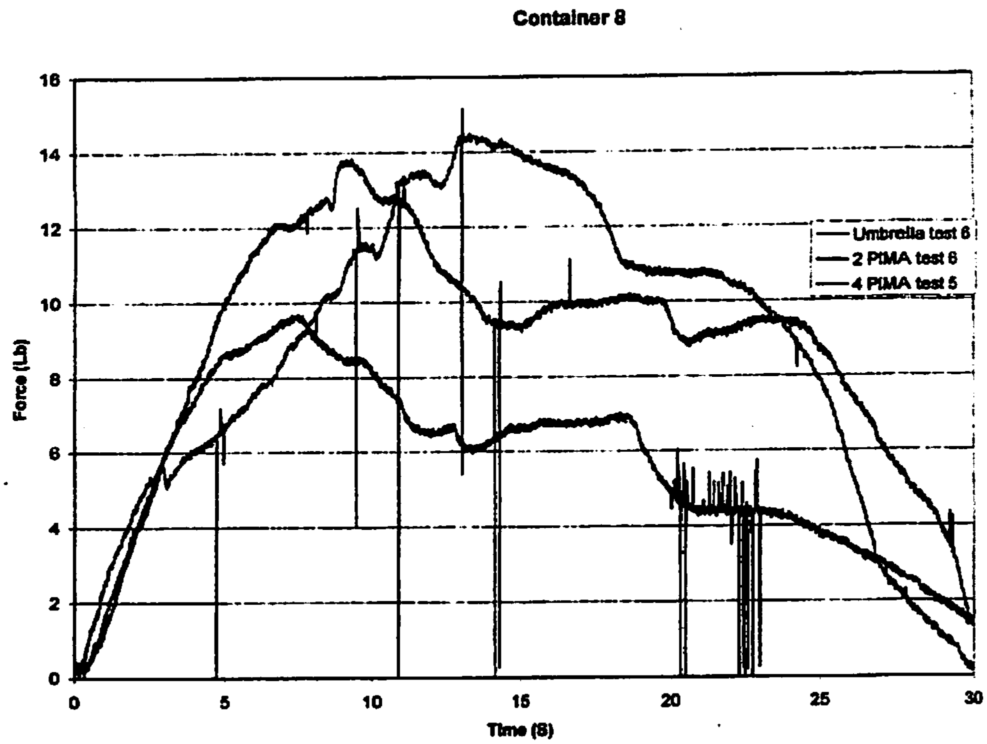

Figure 11. Results of the forces measures for the 2 prong PIMA, 4 prong PIMA and the umbrella dart measured in force over time. The testing medium was uniform due to the fact that all three being darts were pulled from container #8.

The 2 PIMA and umbrella dart types in the same container closely match in force profile. Where as the 4 PIMA behaves the same but has different force profile. The top right graph is the 2 PIMA dart and top let is the umbrella dart which the same types of darts closely resembles the same force profile. The Bottom graph same shape force curve but one dart seemed to hold longer than the other. Darts with the same force profile show consistency in the holding force and behavior for each dart type. The same shape force curve shows consistent behavior with inconsistent holding force patterns.

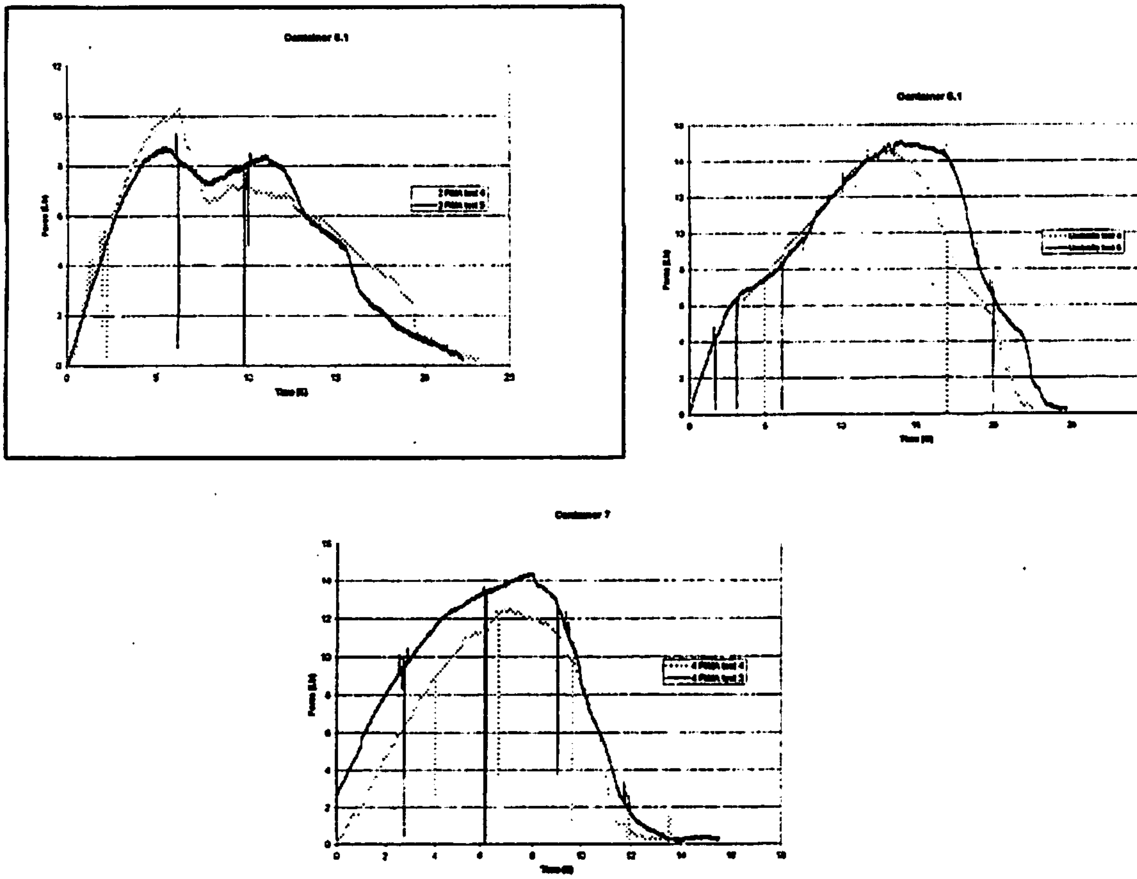

Figure 12a, 12b, and 12c. The three graphs above include the force vs. time results for two of the same darts in the same container. Figure 12a displays the results of two 2 PIMA darts, 12b two umbrella darts, and 12c two 4 PIMA darts.

The gel consistency had a direct effect on the pull test. The gel consistency affects the holding strength and the behavior of the dart. The holding strength between containers changes for darts as a whole. Figure 13 demonstrates the holding strength changes between containers. The behavior of the darts change in the different containers but the behaviors between the darts in different containers stay the same. In Figure 13 the bottom graphs demonstrate how the gel make changes the darts behavior. On the bottom left graph both darts have a jump in force where the bottom right both dart have a smooth positive slope. The behavior being the same between darts allow for the comparison to be made between the darts as long as the medium is the same.

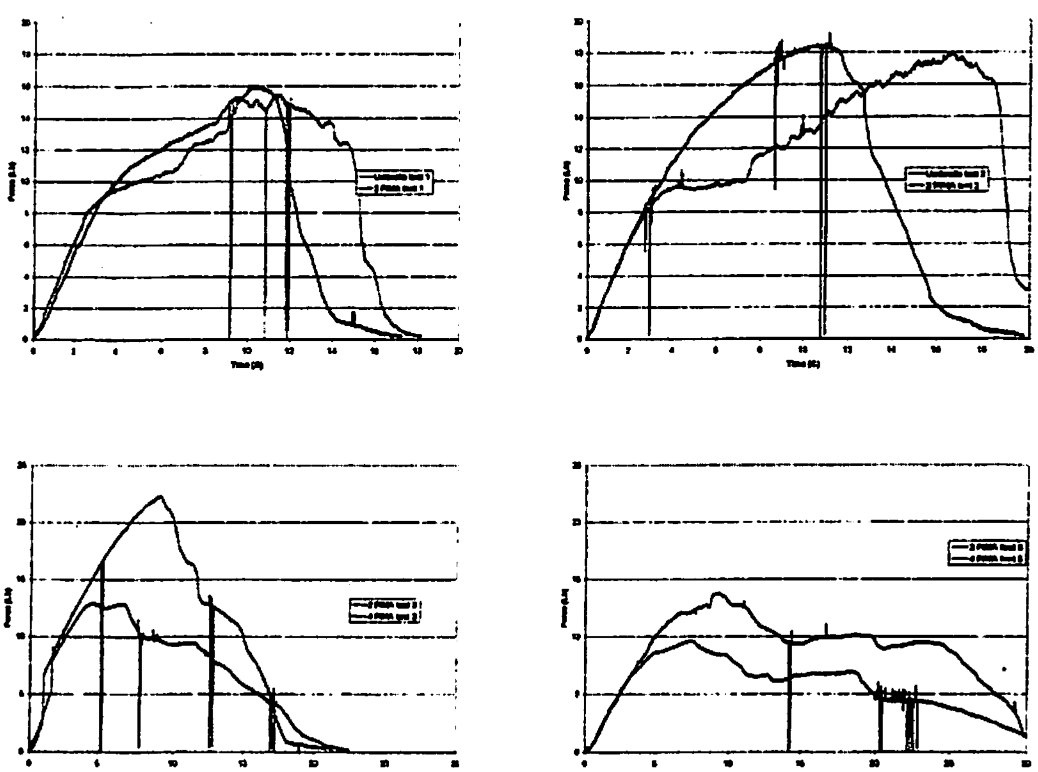

Figure 13. The graphs across from one another compare the same type of darts in different containers. The blue lines are the 4 PIMA dart; red lines are the Umbrella dart; the navy blue lines are the 2 PIMA dart. The top left graph is container 1 and the top right is container 2. The bottom left graph is container 4 and the bottom right graph is container 8 without the Umbrella dart graphed.

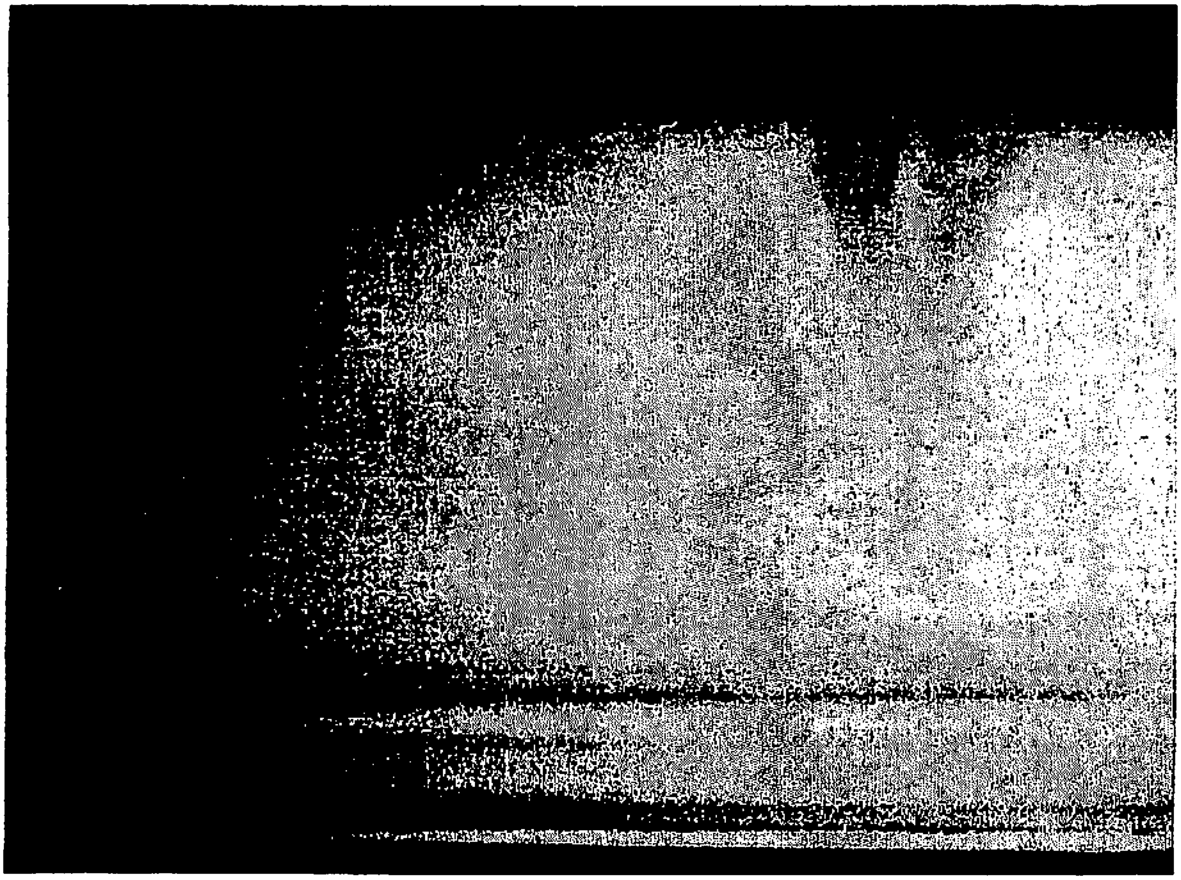

Figure 14. The ballistics gel in container 2 after pull out test. The left impression is a 2 PIMA dart and the right impression is an Umbrella dart.

The gel after the pull out test still has useful data. When the gel is held up to the light, the impression left behind by the pull-out test can be seen. The impression has evidence on the behavior of the dart as it exited the medium. The left impression in figure 8 has evidence to the 2 PIMA dart creating a bubble between the barbs and shaft. The bubble acts as wedge splitting the gel as the dart exits. The evidence in the gel is the way the impression becomes smaller than the dart it's self. By the impression being smaller than the dart a force had to be compressing the gel in the horizontal direction so the barbs could fit through without damaging the gel. A wedge would apply the need horizontal force need when the only apply force was from the vertical direction. The impression in

Figure 14 on the right side is an Umbrella dart. The Umbrella dart impression has evidence of spreading of the barbs and the barbs cutting the gel. The impression has the shape of an upside down Christmas tree. The cone shape shows the barbs flexing out as the dart exits the gel. The lines running up the cone shape are where the barbs were cutting through the gel.

Discussion

Through the use of the POA, ballistics gelatin and four different dart types, experimental conclusions were made that the darts used for PSATs need much improvement. There needs to be funding for a full analysis of the darts in use; that are repeatable test and can be proven. Through the pull out test in ballistic gel there can be a hypothesis made to make improved darts but more tests are needed to prove this hypothesis. The four darts currently in used with PSATs have pros and cons but the combination of the pros can make an improved dart.

The umbrella dart has great concepts that are not used to their full potential. Flexible barbs, small entrance hole, multi barbed system and pointed barb tips are concepts that work well. Holding the concepts back are weak barbs and sharp edges. Flexible barbs allows for a small entrance hole and spreading out as the barbs are pulled out for maximum surface area. The small entrance hole allows for minimum damage to the fish and maximum spreading for the barbs. With the small entrance hole there is more undamaged meat for the barbs to grab into. Maximizing the surface area increases the holding strength of the dart. In Figure 1 the effect of the flexible barbs can be seen in the second positive slope after the bump as the barbs flex out creating more surface area the holding force increases. The multi barb system allows for a grabbling hook effect which anchors in the medium well with multiple barbs creating a high surface area. The more surface area there is the more the force can be dispersed which increases the holding power. The pointed barb tips allow for the barb to dig into the medium without damaging the medium around the barb. The weak barbs are weaker then the medium which allows the barbs to break under strong forces. Three out of ten darts broke a barb during the pull out test. The sharp edges on the barb cause for shearing of the medium making less force required to pull out the dart. The shearing of the medium can be seen in Figure 8.

The two barb PIMA dart is a basic dart concept that was modified for improvement in hold strength. The 2 PIMA dart advantages are strong barbs and rounded edges. The 2 PIMA has some major weaknesses; rounded barb top edge, small surface area, non flexible barbs, and large entrance hole. In the event that the barbs are stronger than the medium the barbs strength should never fail. The round edges stops the cutting effect keeping the medium around the barb undamaged. Having the top edge rounded and shorter barbs takes away from the surface area of the dart by creating a pocket between the barb and shaft of the dart. The pocket weakens the holding strength by acting as a wedge (Figure 8). The barbs have a small surface area to start with before the rounded top edge takes away even more causing there to be more concentrated forces on the medium. The barbs are stiff taking away from the spreading out as they anchor in and causing more damage to the medium on entry. The entry hole caused by the stiffness of the barbs is large in comparison to the size of the barbs leaving more damaged medium for the barbs to anchor into.

The four barb PIMA dart is a modification from the two barb PIMA. In the modification they tried to improve on the weaknesses of the two barb PIMA dart. Two more barbs were added for surface area. The round top edge taken away but other parts of the dart caused that not to matter. Adding the two barbs increased surface area but also increased the entry hole causing more damage to the medium but increased the holding strength of the dart with out changing the behavior of the dart. Figure 5 shows the increased strength compared to the 2 PIMA dart. The top edge failed to help because the material kept the barbs stiff with a curved out barb; causing the sharp edge to have no effect on the medium do to the curved surface being the place of concentrated force. The curved barb along with the extra barbs created a bubble around the dart. The four barb PIMA dart is a great example of a guess and checks method improvement that works as expected but with testing of the darts they would have seen that the modifications should have been made to another dart that is more affective.

The Mike Musyl dart was another modification of the two barb PIMA dart that has great concept that is nullified by some simple problems. Mike Musyl cut of the small barbs and added longer spear barbs. The spear barbs add huge advantages in surface area, and small entrance hole but were very inconsistent. The spear barbs when working properly spread out until the barb is perpendicular to the shaft giving the maximum surface area to the barb while doing little damage to the medium around the barb in comparison to the size of the barb. The spear barbs on entrance fold up along the shaft minimizing the damage done to the medium on entry. The spear barbs are inconsistent in there ability to open properly every time. Some times only one barb will open causing the dart to be unbalance and pull out with less force. The lack of consistence is caused by the barbs being able to go past the center point on the dart making the vertical force being applied holding the barb in a folded position.

An improved design of the umbrella dart could make a superior dart. There are two modifications necessary; fixing the lack of strength of the barbs, stopping the barbs from cutting the medium around the edges. Fixing strength can be solved by making four barbs with increased size equally spaced around the shaft of the barbs. Four barbs still takes advantage of the multi barb system with add more strength to the barb. It also could be solved by using another material that is stronger and has the same flexibility. It is important that the barbs don't lose the flexibility they have now. Flexibility allows the umbrella dart to anchor in the medium so well. The shearing of the medium by the sharp edges can be fixed by changing the barbs to an oval cross-section. The oval shape gives a surface for both the twisting motion and outward force that will distribute the force causing less damage to the medium around the barb. The barb needs to keep the pointed tips so it can spread out in the medium without damaging the medium.

Mike Musyl dart needs more consistency in the opening of the spear barbs. The Improved Musyl dart would have a block of the dart material add right where the barb meets the shaft. The block of material would stop the barb from folding up more than parallel to the shaft ensuring that the barbs would fold out properly when an outward force is applied.

A pull out test with a fibrous material is need for the analysis of barbs. The test gives holding strength of a fibrous material compared to the ballistic gel. Figure 7 proves the behavior changes between a medium that was made to be close to constant. So for a more realistic behavior fibrous materials need to be used. The fibrous material allows the demonstration of the barbs strength to determine if the barbs are too weak and how well the darts anchor in actual tissue. The barb being too weak is demonstrate by barbs breaking as the dart is pulled out of the medium. How well the darts work is demonstrate by the force versus time plot where the maximum force is compared to the drag force of the PSAT tag. If the PSAT drag forces are the close to the same or greater than the holding strength the dart will fail.

Material Strength analysis of the dart material allows for the material with the desired strength and flexibility to be chosen for the dart. The material for each dart needs to behave in a certain way for maximizing the holding strength of the dart. For the umbrella and two PIMA darts the material needs to be as strong as possible with flexibility to about 45 degrees in the vertical direction. The flexibility to 45 degrees allows the barb to go flush against the shaft upon entry creating a small entrance hole then spread out to be perpendicular with the shaft more maximum vertical surface area.

Biologically friendly material analysis allows for a material or coding of the dart to be found that will not be rejected by the flesh. Living organisms have a natural ability do reject material pushing the material out of the flesh or attacking it with chemicals. The rejection of the dart causes the tissue around the dart to become damaged which in return makes it weaker. If the dart has enough holding strength to hold in the weaker material the organism could get sick and/or die leaving the data collected by the PSAT tag garbage.

Live water test can show what is actually failing on the dart system. The PSAT tags are rarely retrieved and the ones that have been located do not have the dart attached to them do to a mechanism that releases the tether and dart when the tag stops moving for a certain period. Without any part of the darting system left on the few tags that are retrieved there is no hard evidence on what exactly is failing in the anchoring system. A live water test where the PSAT tag is attached to a model of the fish and put in a current tank which can simulate the flow on the dart will show which part of the system actually is failing. Knowing which part is failing allows for a direct fix of the problem.

The ballistic gel making needs some improvement done to make in more repeatable. The gel needs to be made in a more consistent way allowing the gel depth and strength to be the same for each test. The insertion depth needs to be about 6 to 8 inches deep so a gel depth should be a foot deep. An actual insertion depth of the dart can confirm what the actual behavior of the barbs is as they are pulled out. The gel strength needs to be the same to get and accurate comparison of the different darts pull out forces; Figure 7 demonstrates how the different strength gel can change the darts behavior.

A finite elemental analysis (FEA) was done on the 2 PIMA dart. The FEA program used was Marc. FEA is the analysis of the elements of a model to make a whole model. The force model generated by Marc has the 2 PIMA darts breaking at 500 Lbs and the dart deforming past usefulness and 250 LBS. The Maximum drag force from the "Investigation of Hydrodynamic Properties and Failure Modes of a Pop-up Satellite Tags used on Atlantic Bluefin Tuna, Thunnus thynnus" was much lower than 250 Lbs therefore the dart material failing on the 2 PIMA is unlikely.

Through testing and analysis of darts used for this experiment we have concluded that further testing needs to be done. The repeatability and standardization of our experiment provides an open doorway for future research to be done on PSATs and the holding strengths of the anchors used to attach them. The data obtained from this experiment has proven that better designs should be constructed for PSAT anchors and pull out tests using the POA should be run before the manufacturing of new dart designs to ensure maximum dart strength.

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Appendix A:

HPW-TP-0601.02
May 1998

TEST PROCEDURE

-Ballistic Gelatin Blocks-

1.0 Background

1.1 The use of gelatin solution as a medium to replicate soft biological tissue has been employed for years in conjunction with wound ballistic studies.

1.2 Solution concentration is most simply defined on a weight percentage basis. Some authorities, however, improperly specify this concentration as the ratio of weight of solute (gelatin) to weight of solvent (water). To properly specify concentration on a weight percentage basis, the ratio of weight of solute to weight of solution (gelatin plus water) is specified. Thus, authorities ignorant of this fact are producing gelatin whose concentrations are, by convention, less than those intended.

1.3 Over a period of years, there has developed a school of thought claiming that a 10 percent weight concentration gelatin solution is more representive of human flesh tissue than a 20 percent weight concentration solution. As of this writing, this issue has not been conclusively resolved.

1.4 Evidence does exist that methods employing water temperatures exceeding 104 degrees Fahrenheit (40 degrees Centigrade) reduce both the gel strength (stiffness) and viscosity of a gelatin solution from that which would otherwise have been produced using relatively cooler water preparation temperatures.

2.0 Objective

2.1 The objective of this procedure is to promulgate a method which, when used, produces a gelatin solution representive of the character of human flesh tissue specified by authoritative literature.

3.0 Discussion

3.1 This procedure specifies the use of Ordnance Type 250A gelatin. This is a Type A gelatin manufactured expressly for ballistic testing usage, and possesses a nominal Bloom rating (gel strength) of 250 grams.

3.2 The characterization of the gelatin solution concentration on a weight percentage basis is based on the ratio of the weight of granulated gelatin to the combined weight of granulated gelatin and water.

3.3 The method specified herein is for formulation of 10 percent weight concentration (1 part solute to 9 parts solvent) gelatin solution only. Formulation of 20 percent weight concentration gelatin solution at these relatively cooler water temperatures precludes adequate hydration of all of the gelatin granules during the hydration period of formulation (see formulation below).

4.0 Formulation Procedure

4.1 Table I provides a work sheet to calculate the correct quantities of granulated gelatin and water for any volume of container. Use of biological mold inhibitors, such as propionic acid or cinnamon oil, is optional.

TABLE I. FORMULATION WORK SHEET

1. Weight of mold	:__________	grams
2. Fill mold with water.		
3. Weight of mold + water	:__________	grams
4. Weight of water	:__________	grams
5. Weight of gelatin	:__________	grams (a)

(a) To determine the weight of gelatin for a 10 percent concentration, divide the weight of water by 9.

4.2 Rigid adherence to the following procedure is important:

4.2.1 Begin the mixing process with water at 45-50°F (7-10°C).

4.2.2 Add 5 ml of propionic acid or cinnamon oil (optional).

4.2.3 Add gelatin to water - never add water to gelatin.

4.2.3.1 Stir gently to avoid entrapping air.

4.2.3.2 Stir only until all particles of gelatin are wetted.

4.2.4 Let stand (hydrate) at 45-50°F (7-10°C) for two hours.

4.2.5 Heat solution to 100°F (38°C). DO NOT HEAT OVER 104°F (40°C).

4.2.6 Pour into mold and store at 45-50°F (7-10°C) for a minimum of twenty hours.

4.2.7 Remove gelatin from mold. Application of hot water to outside of mold will ease removal.

4.2.8 Conduct testing within twenty minutes of removal from storage temperature (45-50°F).

4.2.9 For improved optical quality, minor surface irregularities may be eliminated by smoothing with warm water.

5.0 <u>Reconstituted Blocks</u>

5.1 In the interest of economy, gelatin blocks may be reused to make new blocks by heating to--and maintaining at--100 degrees Fahrenheit. Once the gelatin block dissolves into solution again, the above procedure may then be repeated.

6.0 <u>Long Term Storage</u>

6.1 Remove from mold, seal in airtight bag, and store at 39°F (4°C).

7.0 <u>Materials</u>

7.1 The following materials are to be used:

7.1.1 Ordnance Type 250A gelatin; Kind and Knox Gelatin, Inc.; Sioux City, Iowa.

7.1.2 Water; potable.

7.1.3 Propionic acid; Fisher Scientific; Pittsburgh, Pennsylvania.

7.1.4 Cinnamon oil; Lorann Oils, Inc.; Lansing, Michigan.

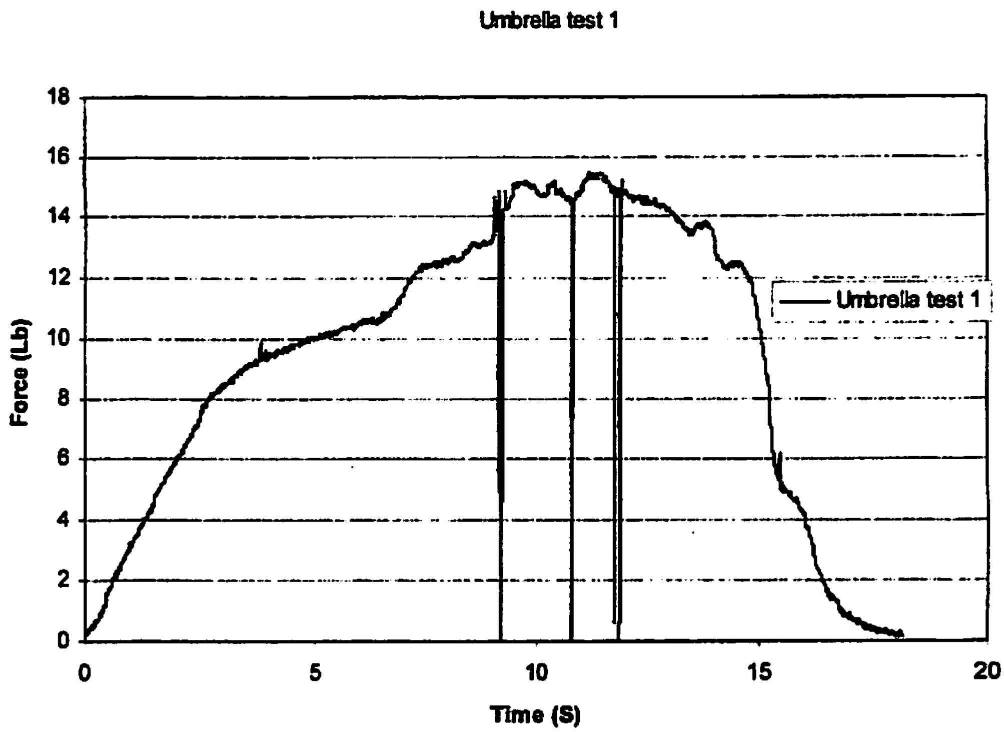
Appendix B

Dart Type	Test #	Container #	File Name	Dart Status	Depth in Gel cm	# of Data Points	Date Pullec
Umbrella	1	1	2	1 broken barb	8.4	1818	4\13\0
Umbrella	2	2	4	NVD	8.7	2071	4\13\0
Umbrella	3	3	7	NVD	8.7	1953	4\13\0
Umbrella	4	5.1	10	NVD	9.6	2232	4\13\0
Umbrella	5	5.1	11	NVD	9.7	2463	4\13\0
Umbrella	6	8	18	NVD	12.5	3141	4\13\0
Umbrella	7	6.2	20	NVD	9.6	2417	4\14\0
Umbrella	8		24	1 broken barb	12.3	3576	4\18\0
Umbrella	9		26	NVD	10.4	2719	4\18\0
Umbrella	10		29	2 broken barbs, very bent	12.7	4378	4\18\0
2 PIMA	1	1	3	NVD	8.1	1728	4\13\0
2 PIMA	2	2	5	NVD	9.2	1974	4\13\0
2 PIMA	3	4	8	NVD	10	2241	4\13\0
2 PIMA	4	6.1	12	NVD	9.6	2332	4\13\0
2 PIMA	5	6.1	15	NVD	9.9	2245	4\13\0
2 PIMA	6	8	16	NVD	12.6	3401	4\13\0
2 PIMA	7	5.2	22	NVD	9.2	2418	4\14\0
2 PIMA	8		23	NVD	12.4	3402	4\18\0
2 PIMA	9		25	NVD	10.2	2653	4\18\0
2 PIMA	10		30	NVD	10.3	2752	4\18\0
4 PIMA	1	3	6	NVD	9	1322	4\13\0
4 PIMA	2	4	9	NVD	9.5	2128	4\13\0
4 PIMA	3	7	14	NVD	7.8	1556	4\13\0
4 PIMA	4	7	13	NVD	8.2	1419	4\13\0
4 PIMA	5	8	17	NVD	11.7	3329	4\13\0
4 PIMA	6	6.2	19	NVD	9.7	2399	4\14\0
4 PIMA	7	5.2	21	NVD	8.9	2476	4\14\0
4 PIMA	8		32	NVD	11	2512	4\18\0
4 PIMA	9		28	NVD	12.3	3357	4\18\0
4 PIMA	10		31	NVD	10.1	2546	4\18\0
Musyl	1		27	stuck in gel	18.8	5043	4\18\0
Musyl	2		33	only 1 flopper caught	14.2	3605	4\18\0
Musyl	3		34	only 1 flopper caught	14.9	3362	4\18\0

*NVD= No Visible Damage

Dart Type	Test #	Container #	File Name Dart Status	Depth in Gel cm	# of Data Points	Date Pulled
Umbrella	1	1	21 broken barb	8.4	1818	4\13\0
Umbrella	2	2	4NVD	8.7	2071	4\13\0
Umbrella	3	3	7NVD	8.7	1953	4\13\0
Umbrella	4	5.1	10NVD	9.6	2232	4\13\0
Umbrella	5	5.1	11NVD	9.7	2463	4\13\0
Umbrella	6	8	18NVD	12.5	3141	4\13\0
Umbrella	7	6.2	20NVD	9.6	2417	4\14\0
Umbrella	8		241 broken barb	12.3	3576	4\18\0
Umbrella	9		26NVD	10.4	2719	4\18\0
Umbrella	10		292 broken barbs, very bent	12.7	4378	4\18\0
2 PIMA	1	1	3NVD	8.1	1728	4\13\0
2 PIMA	2	2	5NVD	9.2	1974	4\13\0
2 PIMA	3	4	8NVD	10	2241	4\13\0
2 PIMA	4	6.1	12NVD	9.6	2332	4\13\0
2 PIMA	5	6.1	15NVD	9.9	2245	4\13\0
2 PIMA	6	8	16NVD	12.6	3401	4\13\0
2 PIMA	7	5.2	22NVD	9.2	2418	4\14\0
2 PIMA	8		23NVD	12.4	3402	4\18\0
2 PIMA	9		25NVD	10.2	2653	4\18\0
2 PIMA	10		30NVD	10.3	2752	4\18\0
4 PIMA	1	3	6NVD	9	1322	4\13\0
4 PIMA	2	4	9NVD	9.5	2128	4\13\0
4 PIMA	3	7	14NVD	7.8	1556	4\13\0
4 PIMA	4	7	13NVD	8.2	1419	4\13\0
4 PIMA	5	8	17NVD	11.7	3329	4\13\0
4 PIMA	6	6.2	19NVD	9.7	2399	4\14\0
4 PIMA	7	5.2	21NVD	8.9	2476	4\14\0
4 PIMA	8		32NVD	11	2512	4\18\0
4 PIMA	9		28NVD	12.3	3357	4\18\0
4 PIMA	10		31NVD	10.1	2546	4\18\0
Musyl	1		27stuck in gel	18.8	5043	4\18\0
Musyl	2		33only 1 flopper caught	14.2	3605	4\18\0
Musyl	3		34only 1 flopper caught	14.9	3362	4\18\0

*NVD= No Visible Damage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Force (Lb)
Time (S)
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6
8
10
12
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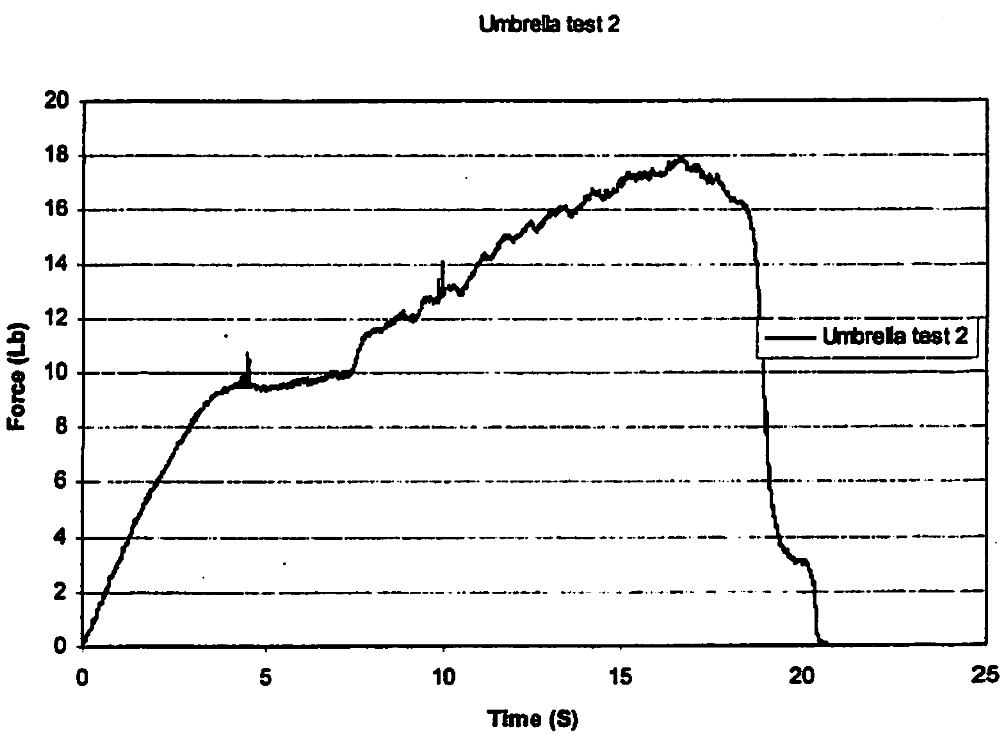
18
0
5
10
15
20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Time (S)
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18
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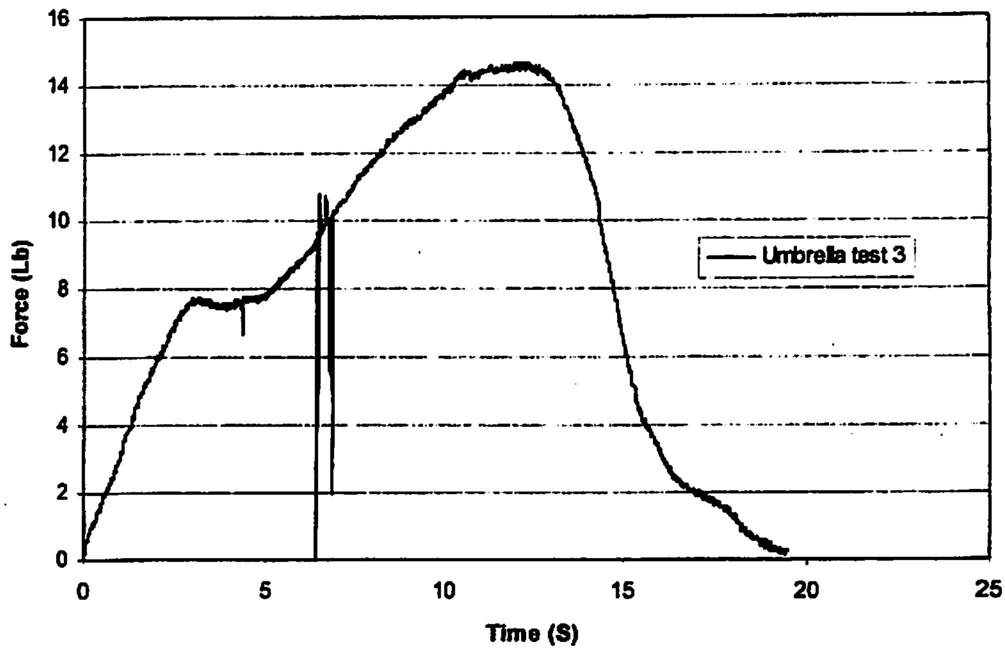
5
10
15
20
25

Umbrella test 3



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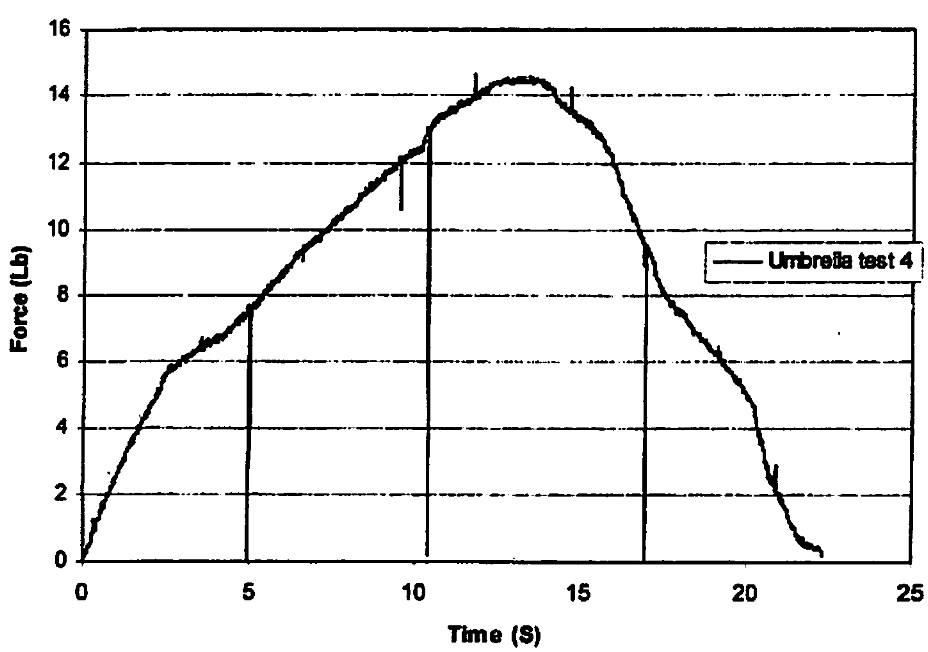

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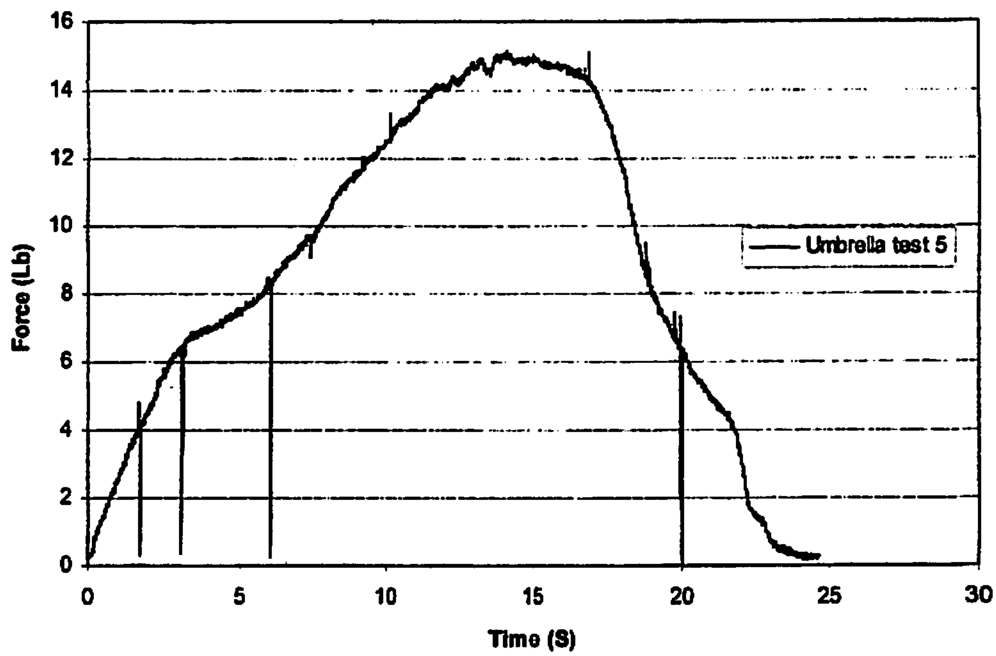

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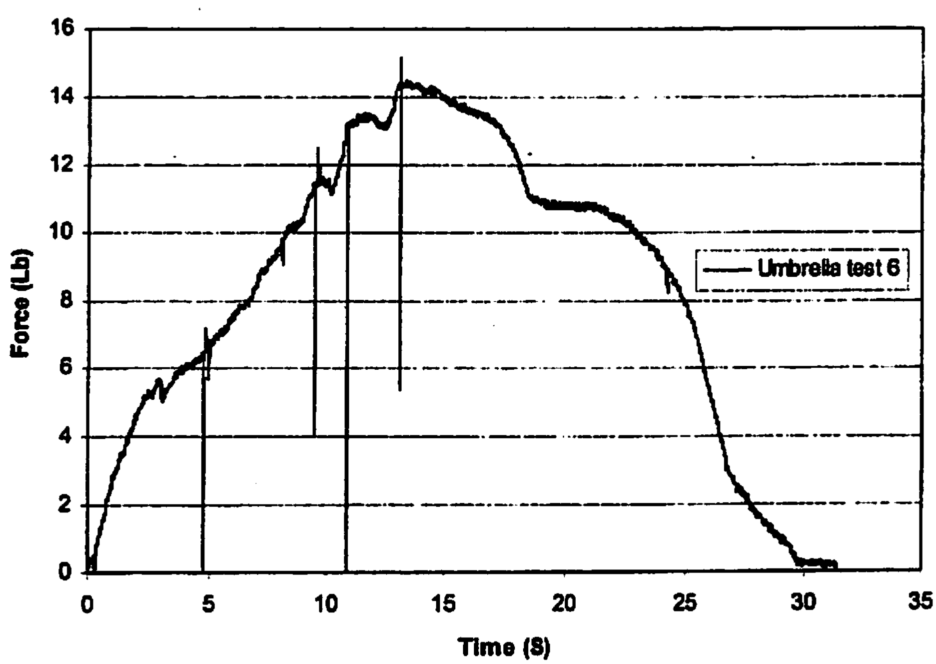

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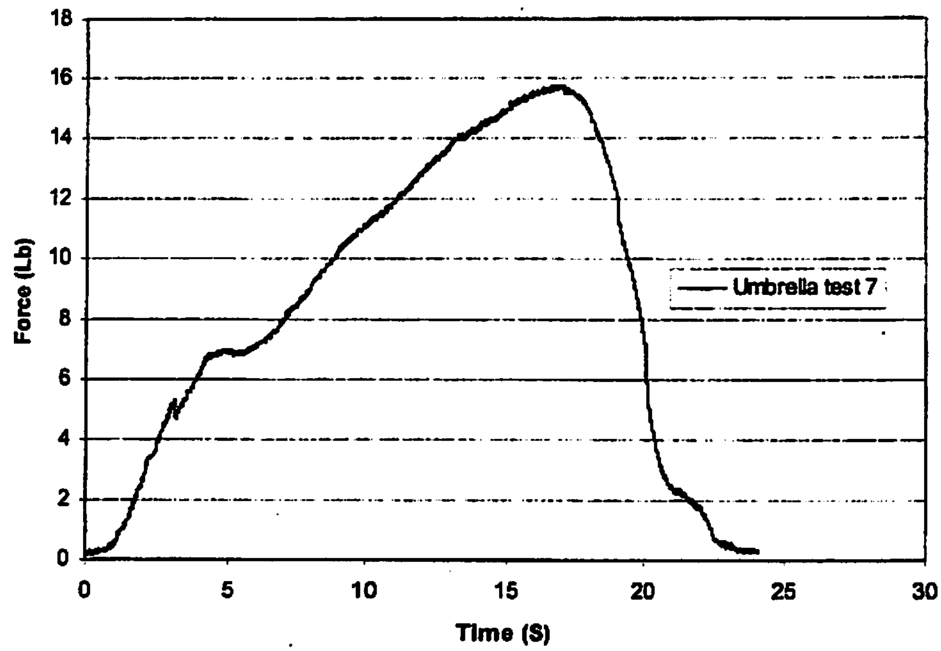

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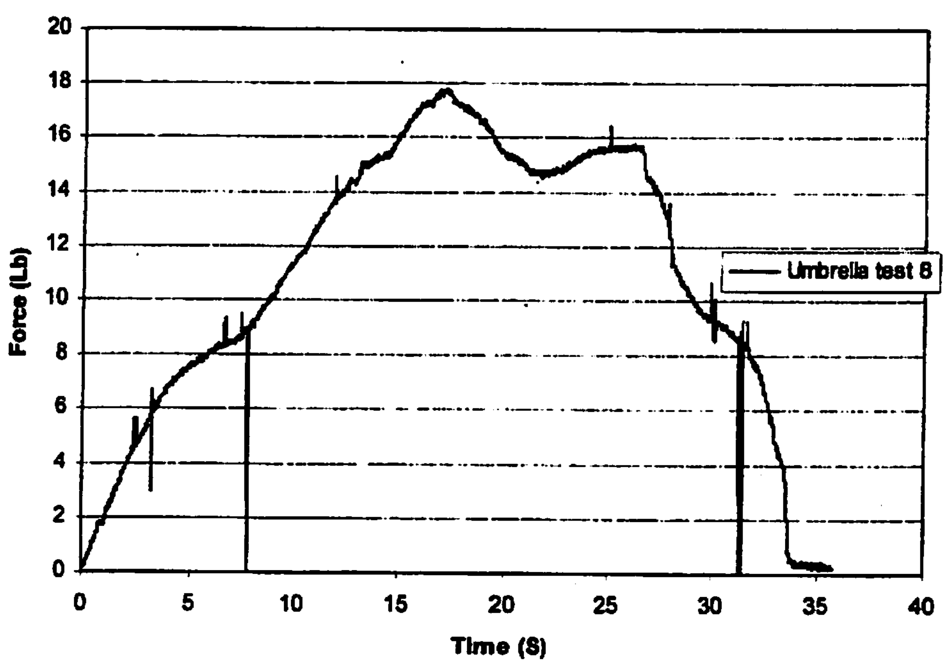
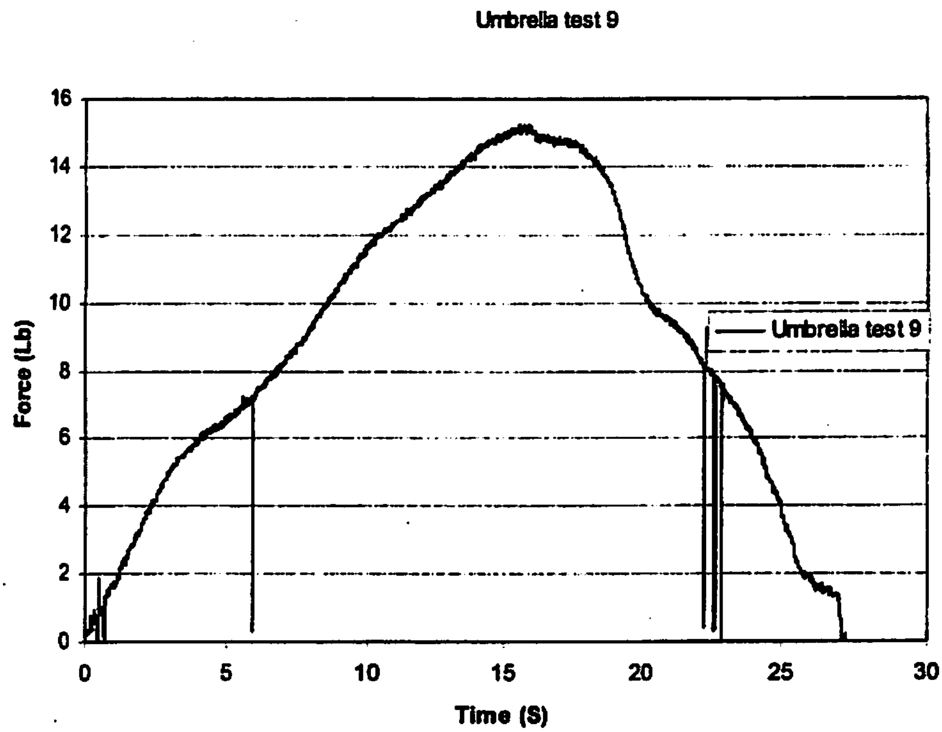
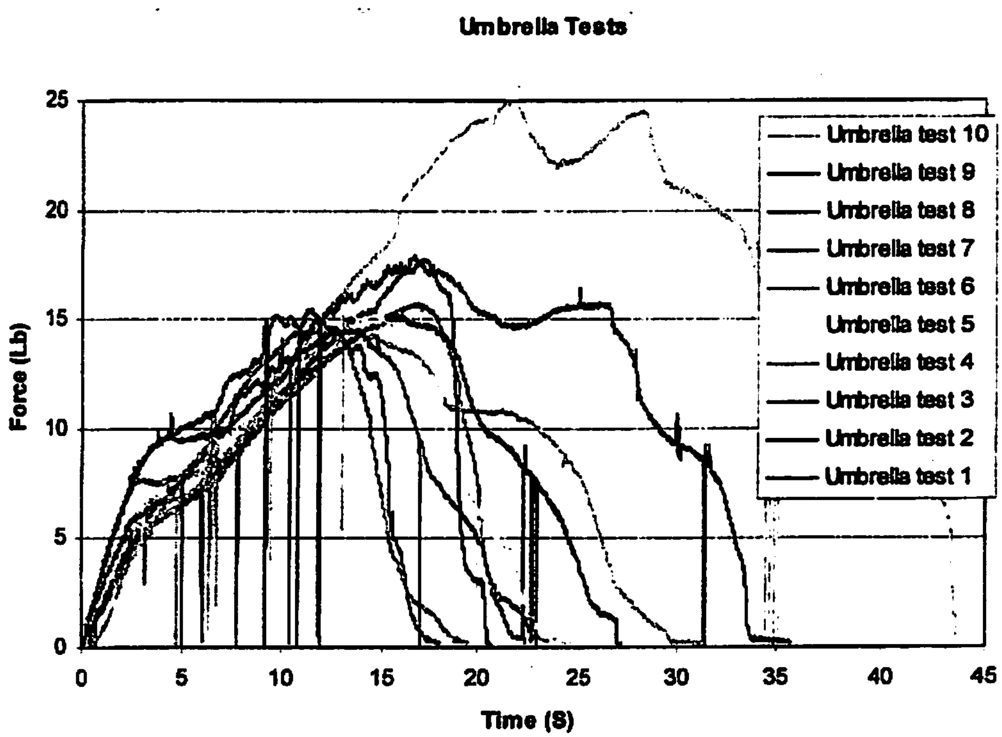


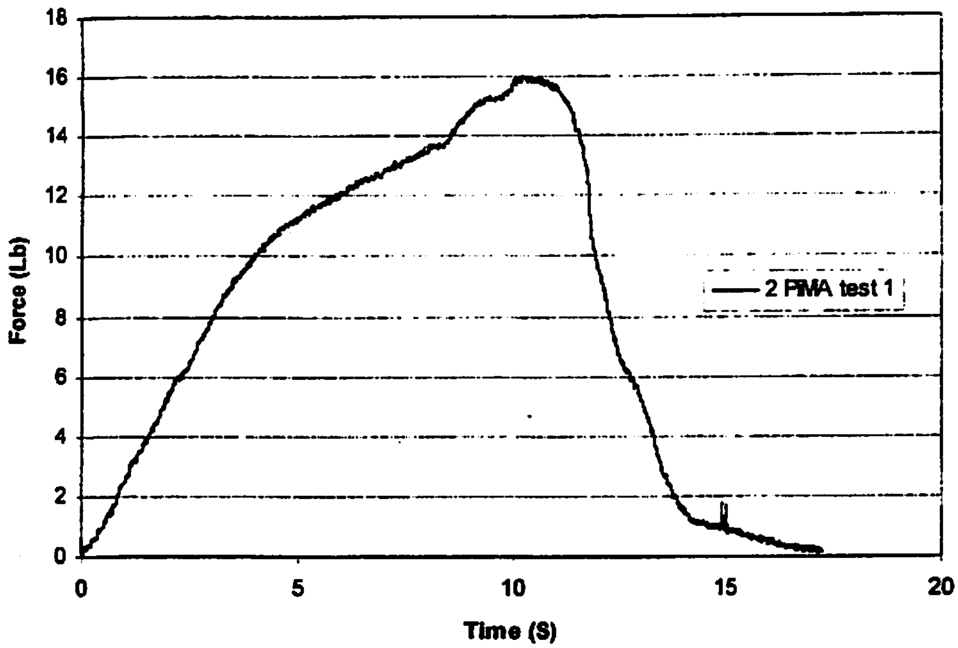


Umbrella test 9
Force (Lb)
Time (S)
Umbrella test 9



Umbrella Tests
Force (Lb)
Time (S)
Umbrella test 10
Umbrella test 9
Umbrella test 8
Umbrella test 7
Umbrella test 6
Umbrella test 5
Umbrella test 4
Umbrella test 3
Umbrella test 2
Umbrella test 1

2 PIMA test 1



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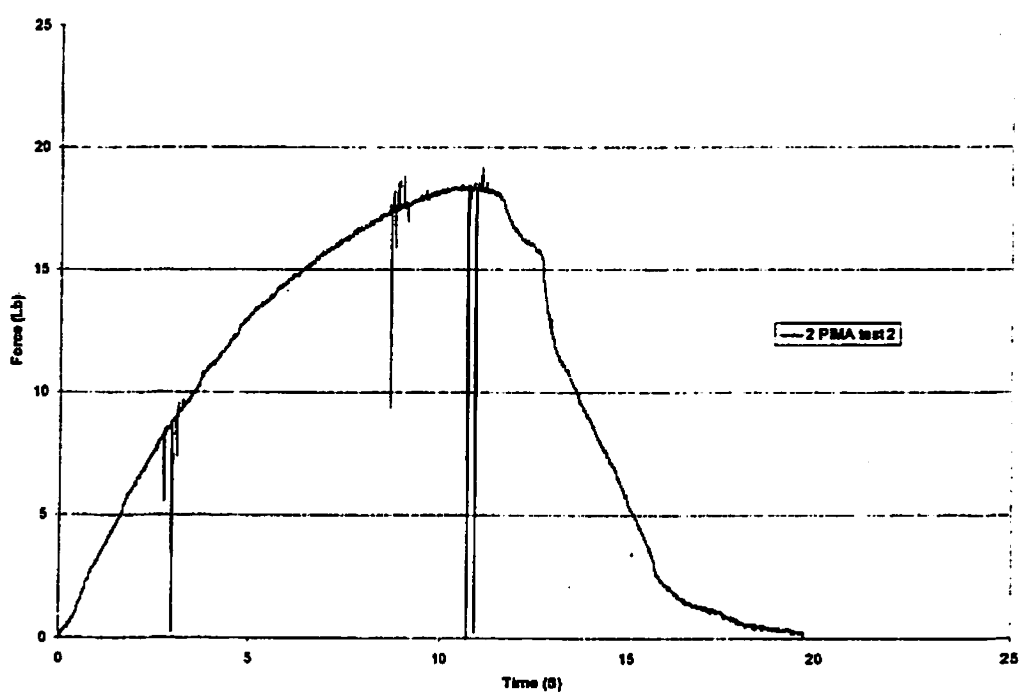

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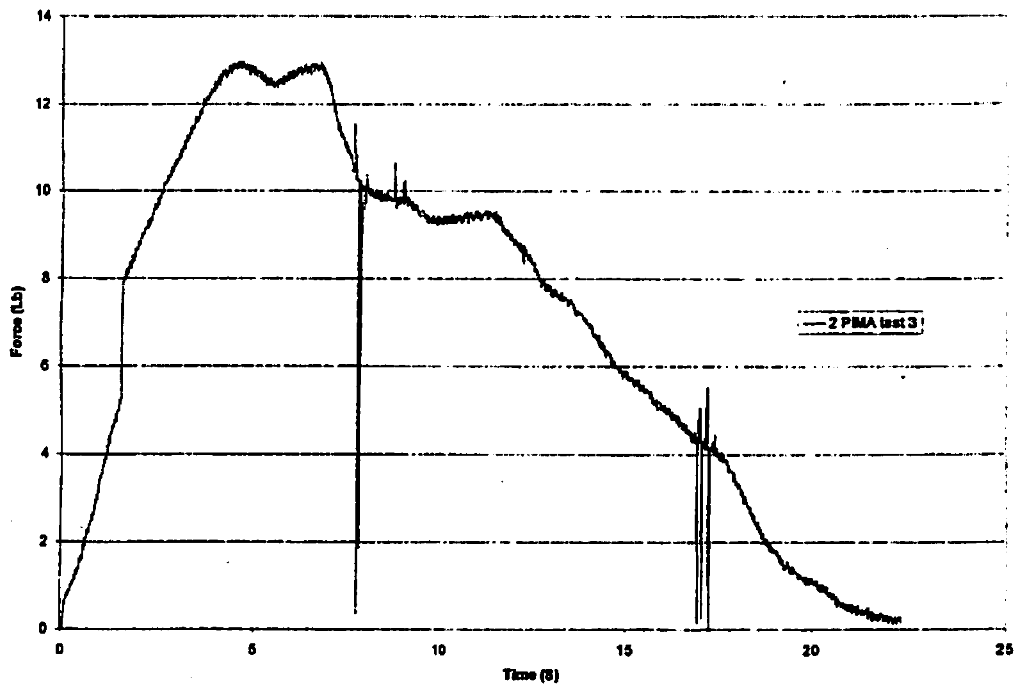

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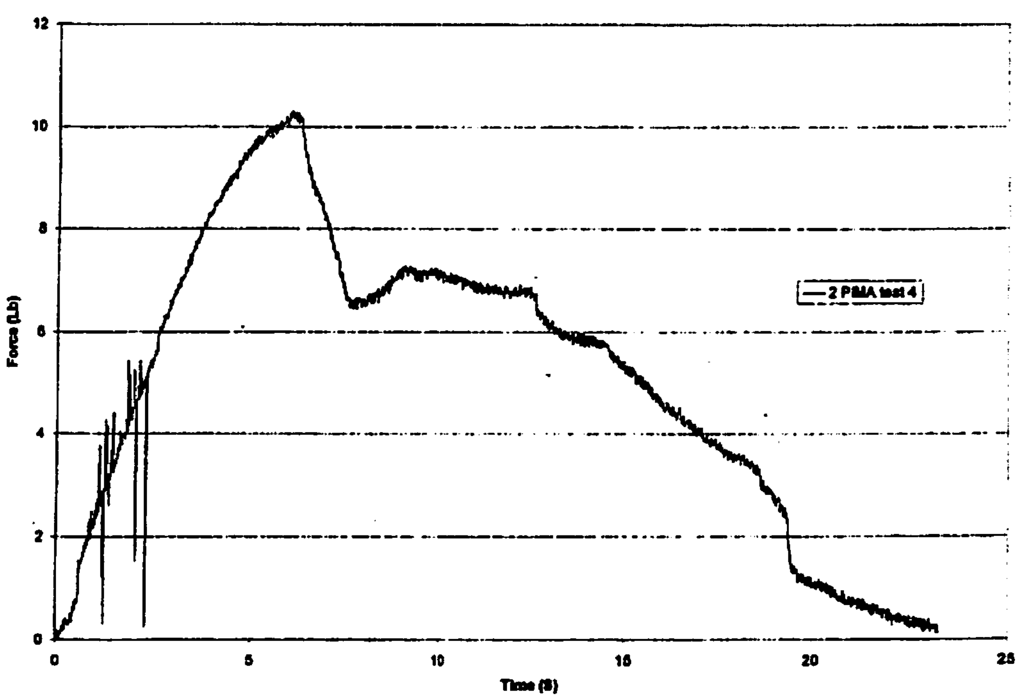

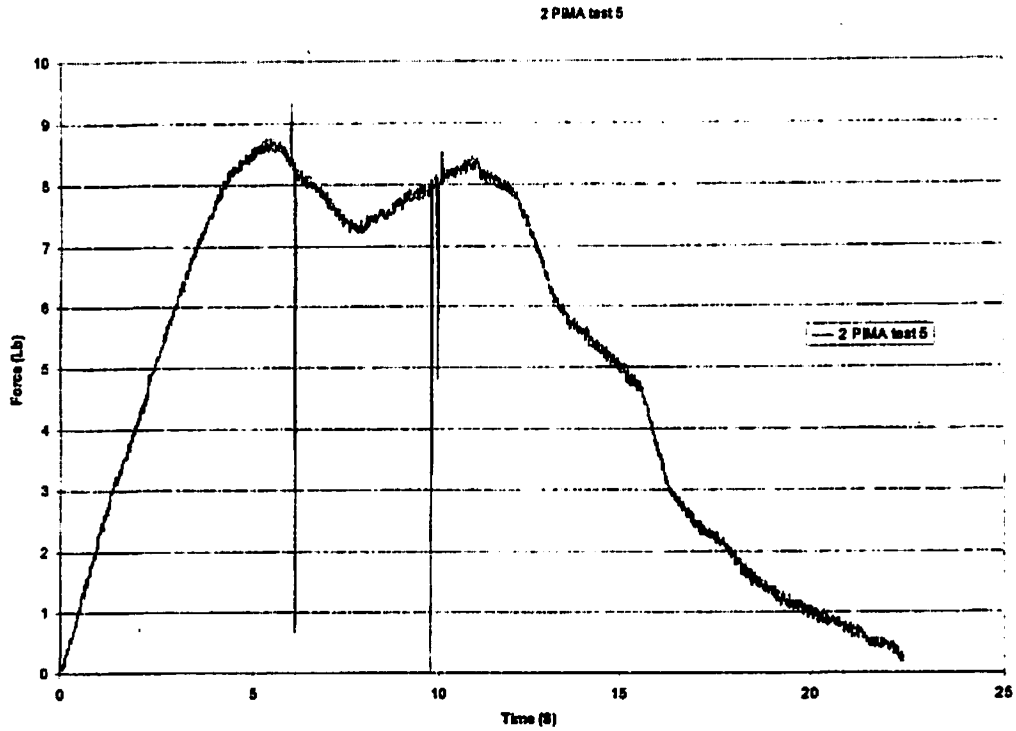
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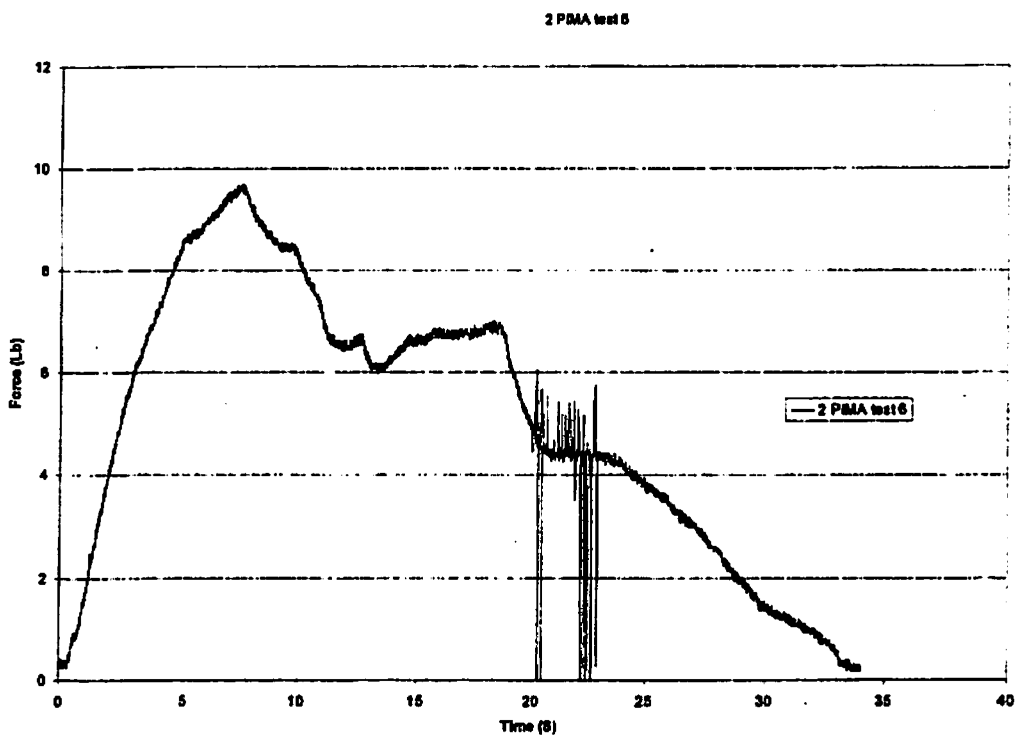
Force (Lb)
Time (S)
2 PMA test 5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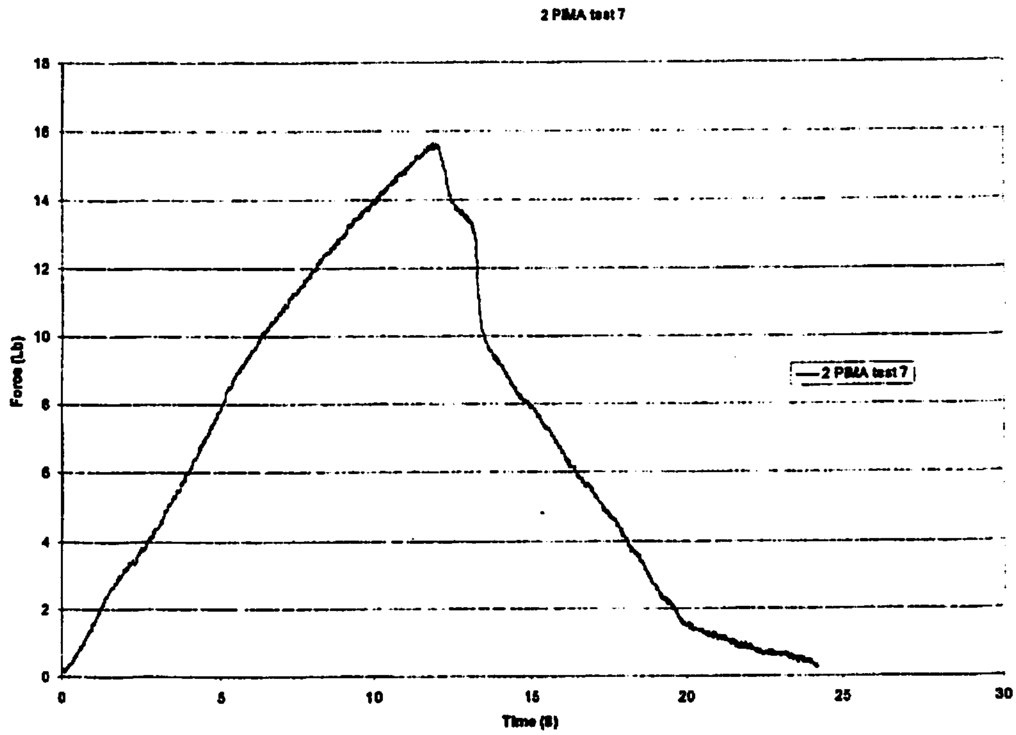
Force (Lb)
Time (S)
2 PMA test 6



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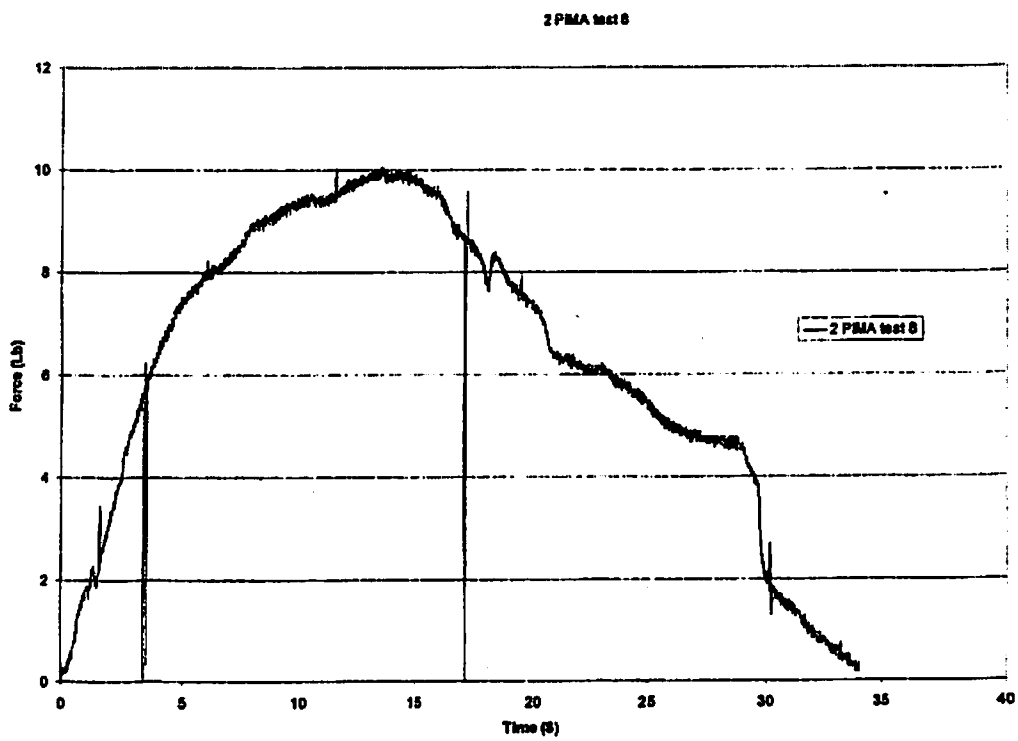
Force (Lb)
Time (S)
2 PMA test 7



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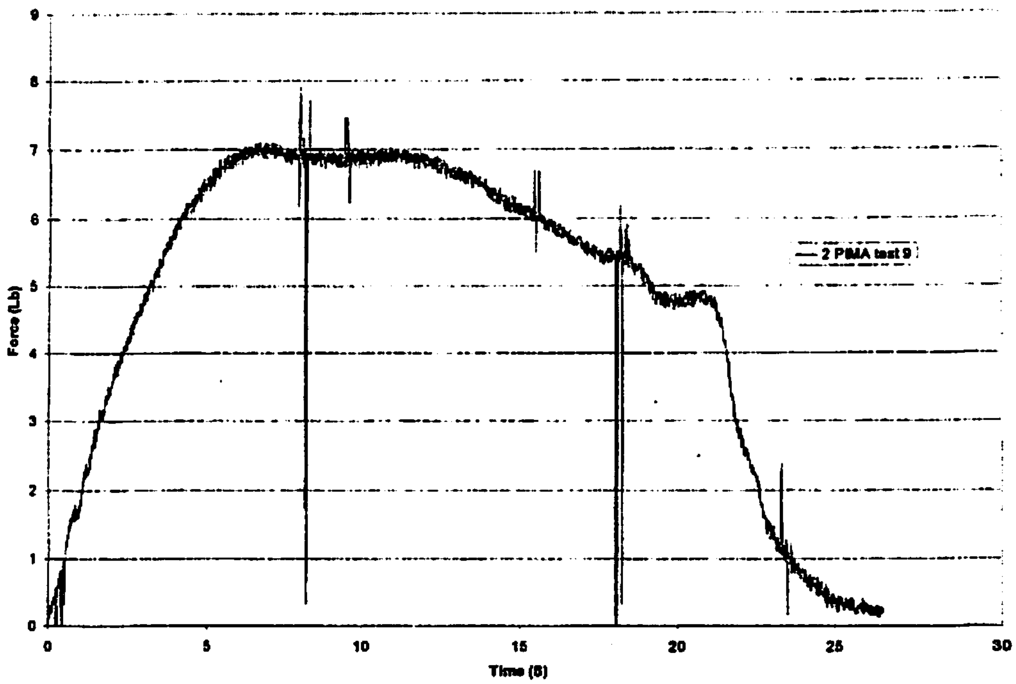
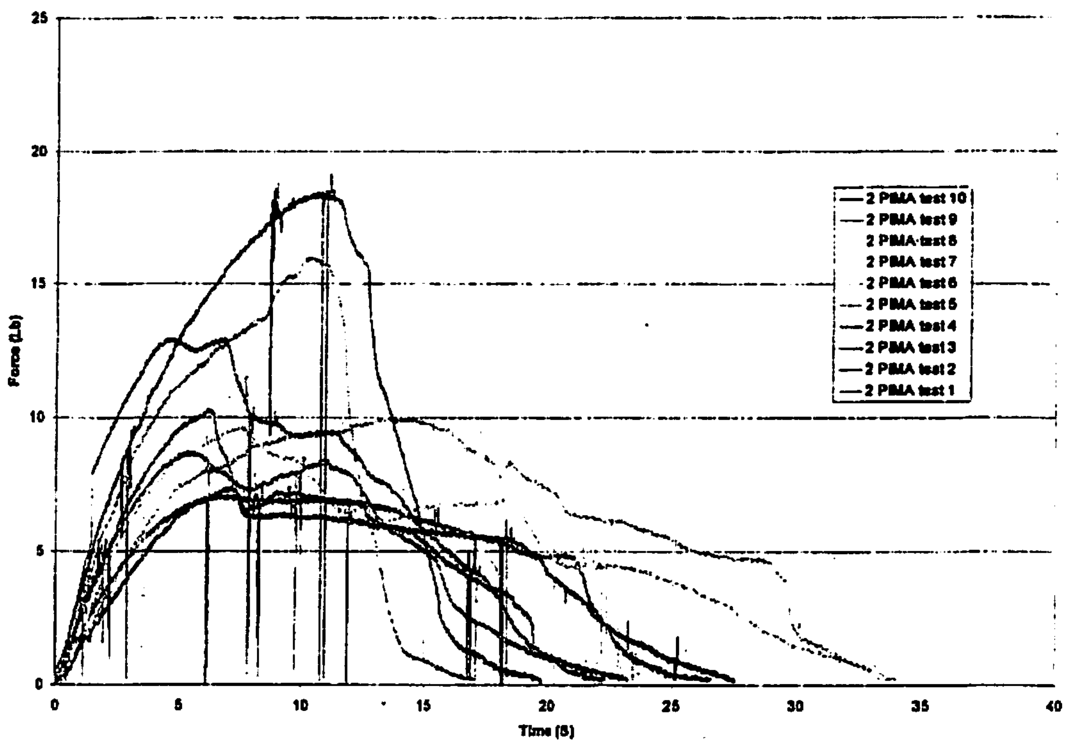
Force (Lb)
Time (S)
2 PMA test 8

2 PMA test 9



Force (Lb)
Time (S)
2 PMA test 9



Force (Lb)
Time (S)
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2 PMA test 9
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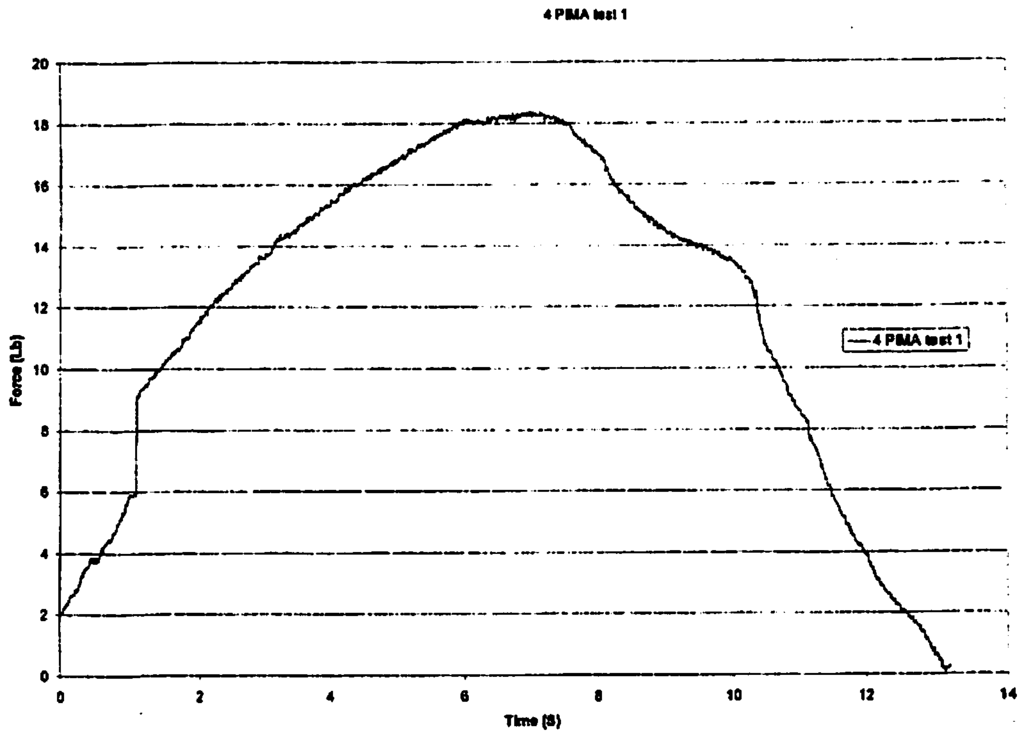
2 PMA test 2
2 PMA test 1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Time (S)
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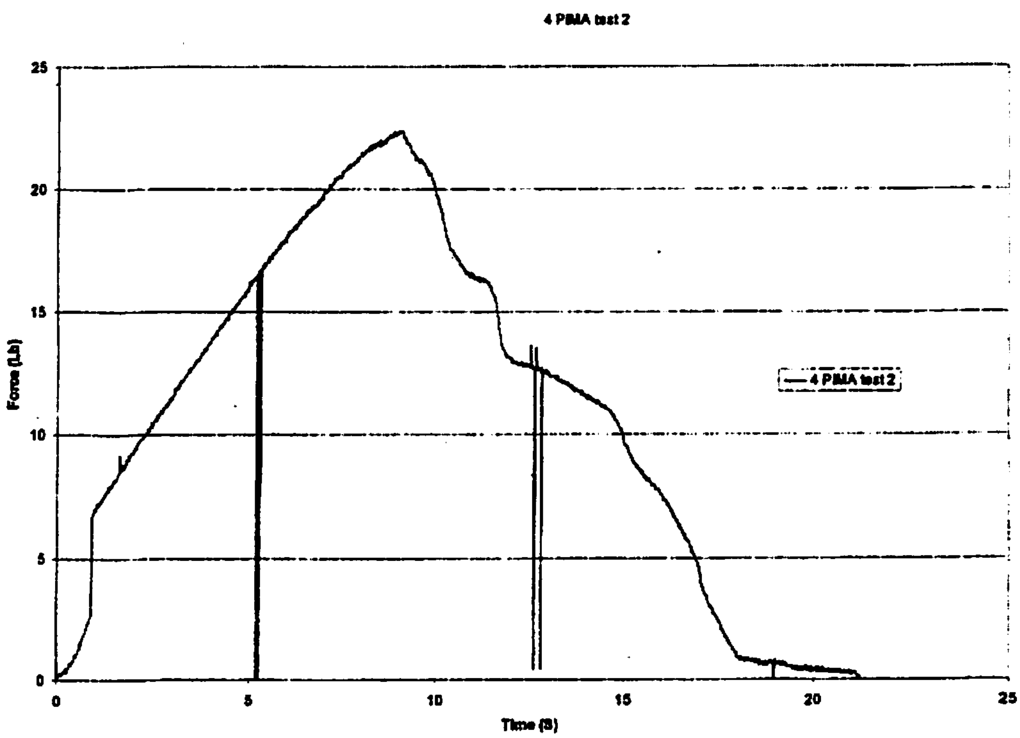
2
4
6
8
10
12
14
16
18
20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Time (S)
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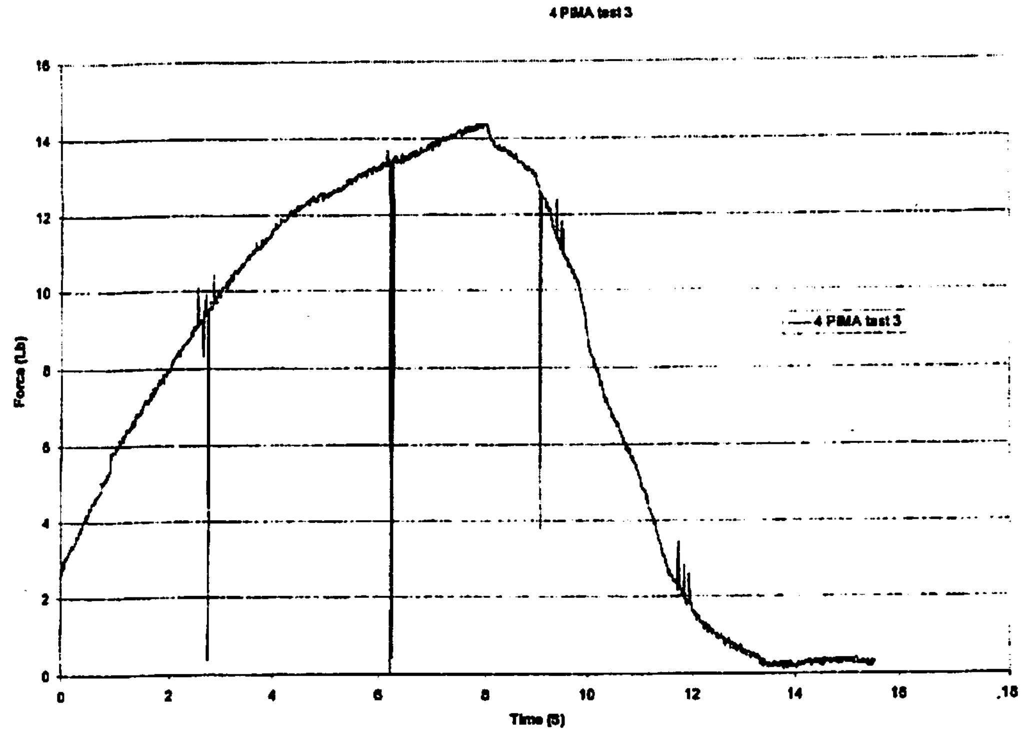
5
10
15
20
25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Time (S)
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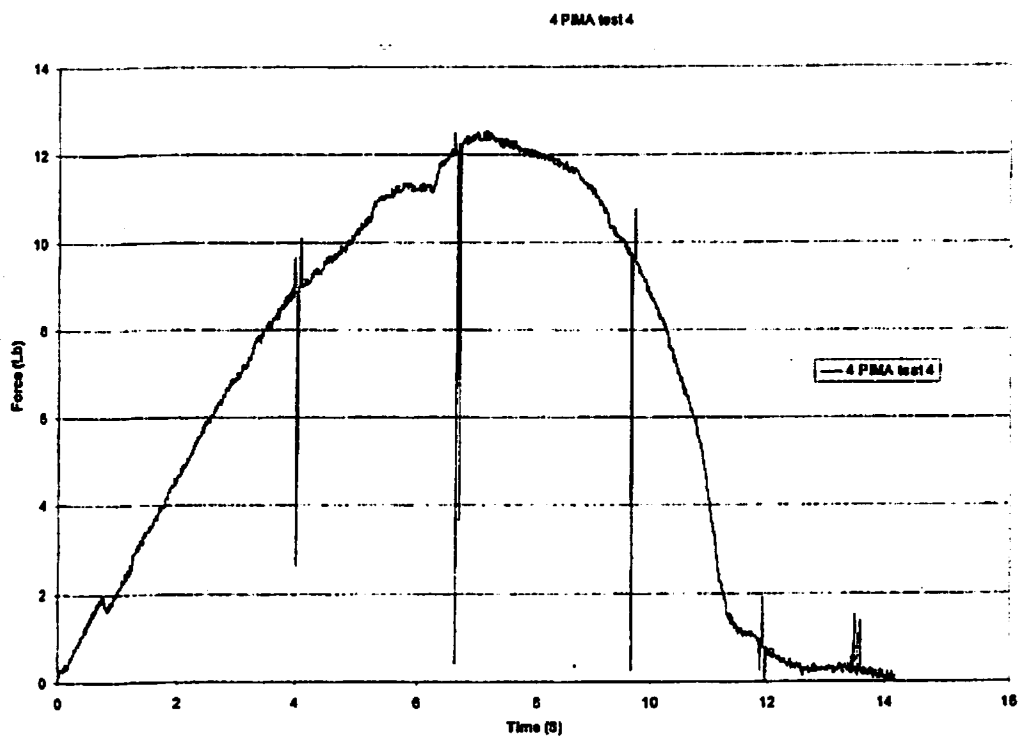
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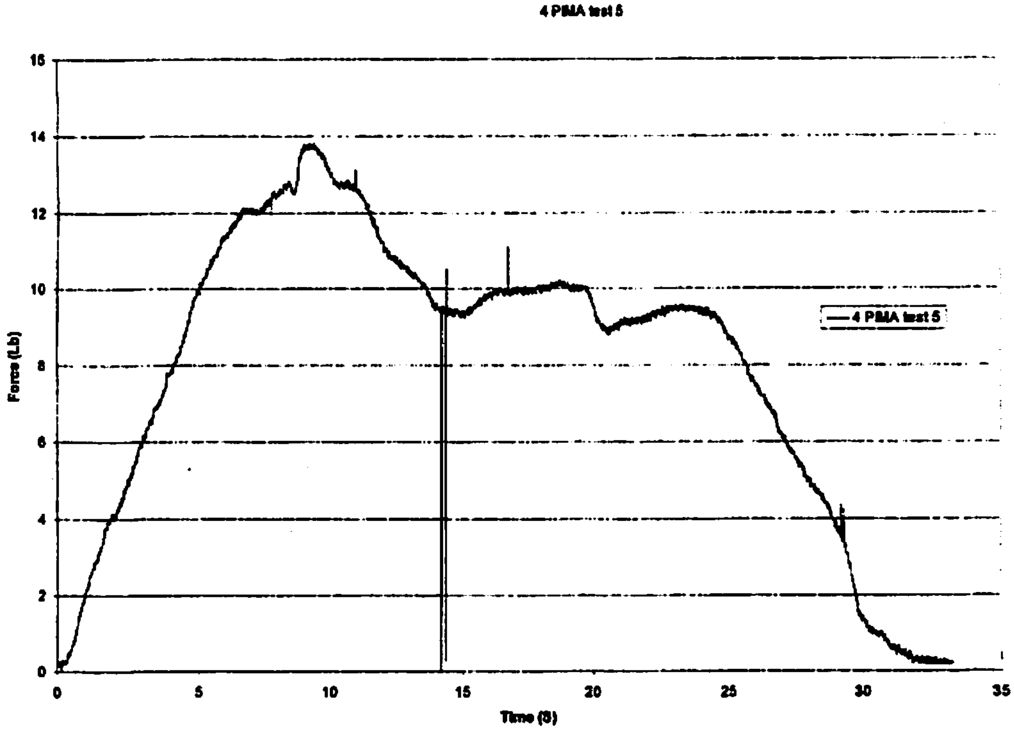
Time (S)
4 PMA test 4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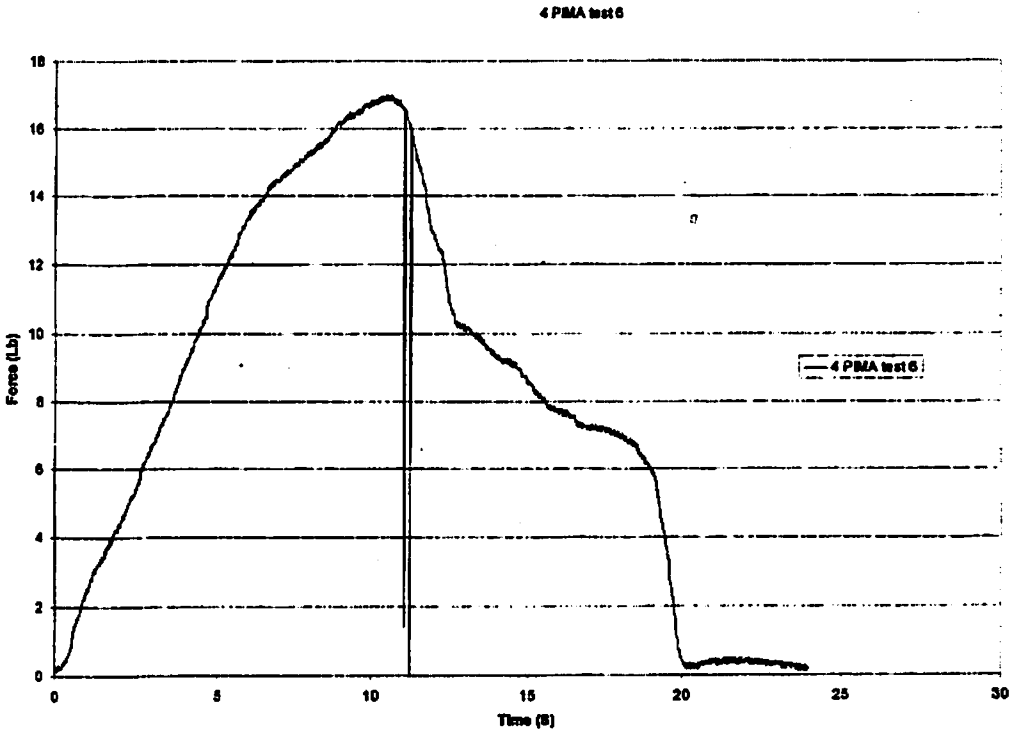
Time (S)
4 PMA test 5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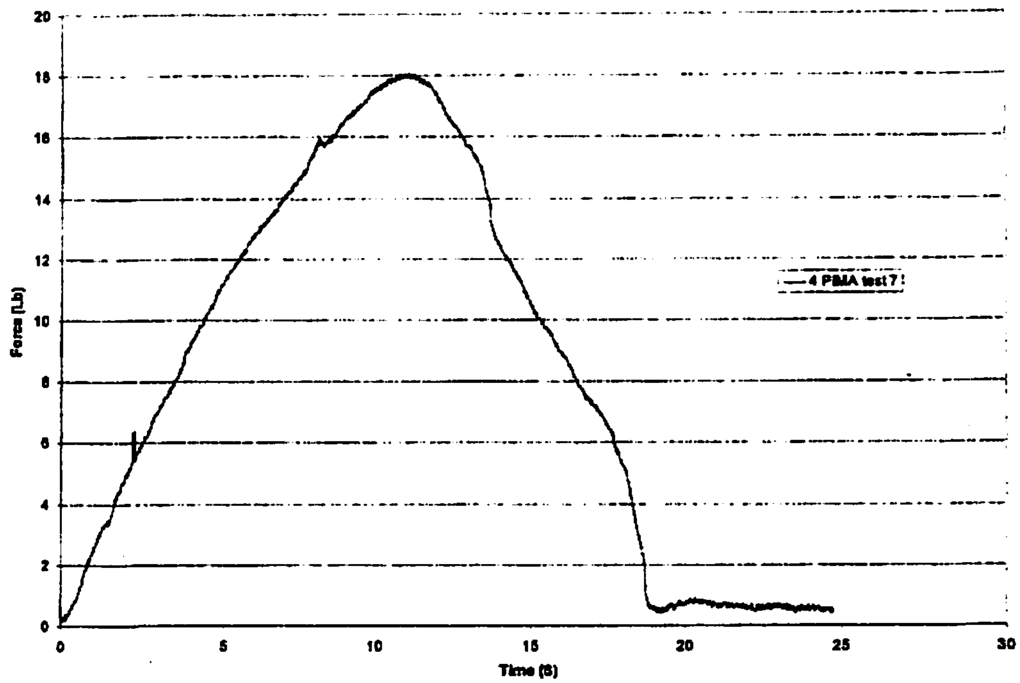
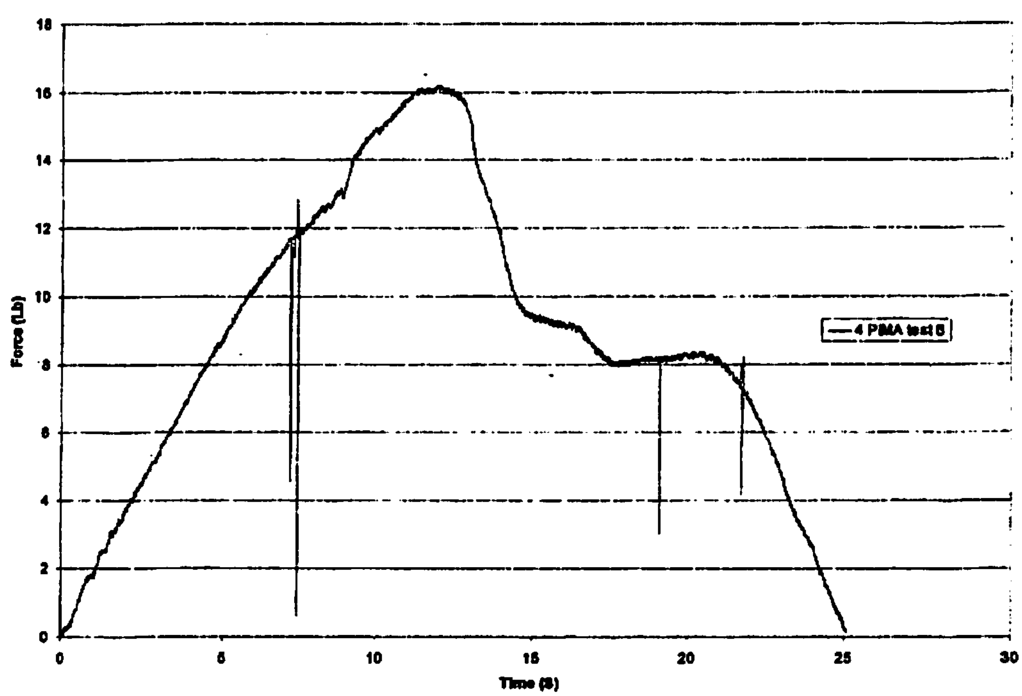
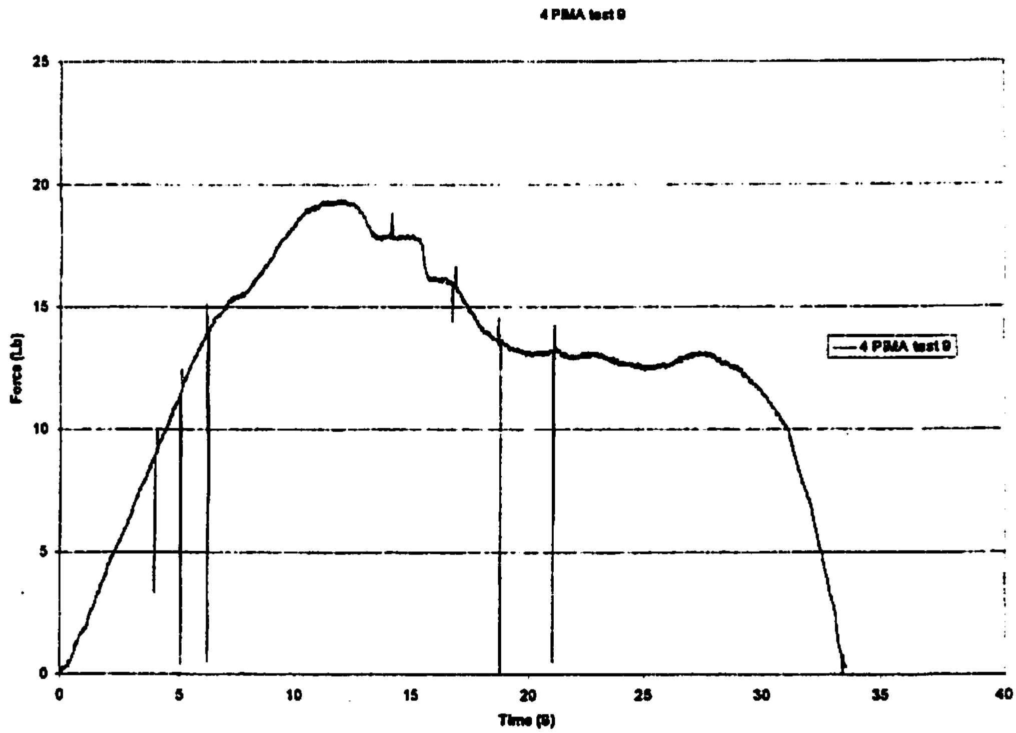
Force (Lb)
Time (S)
4 PMA test 6

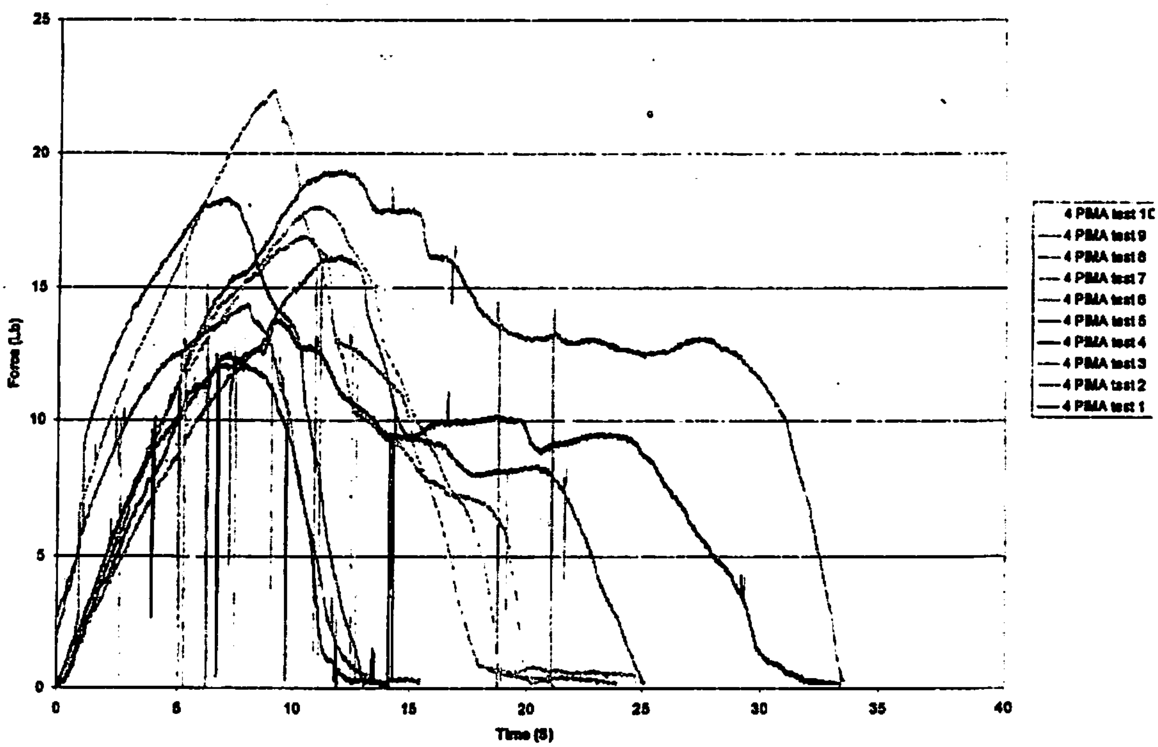
4 PMA test 7



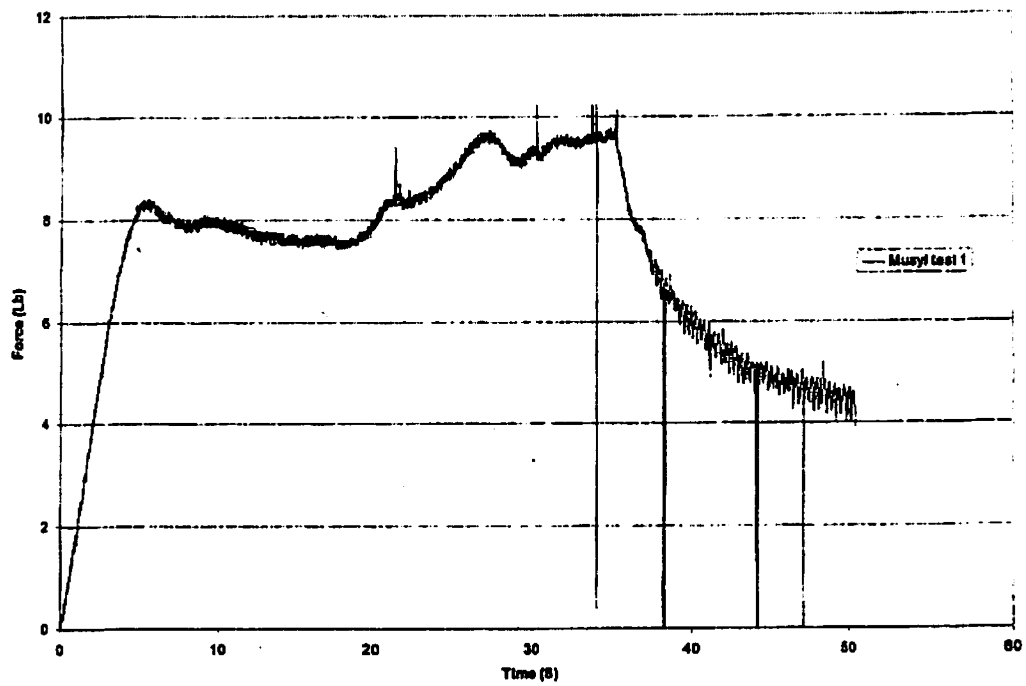
4 PMA test 8



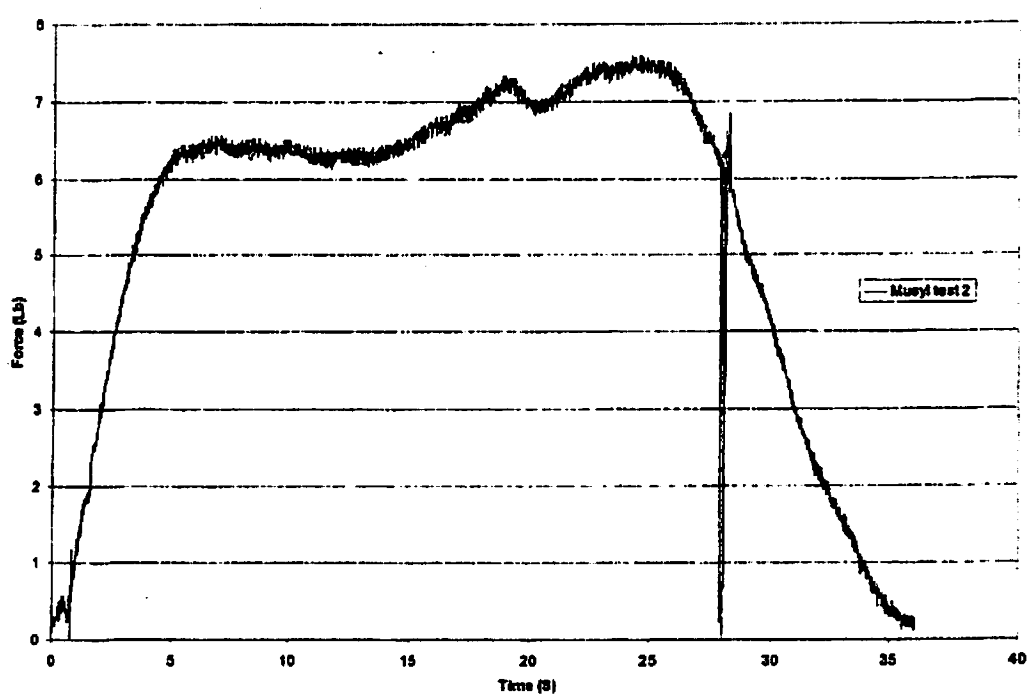

4 PMA test 9
Force (Lb)
Time (S)
4 PMA test 9
0
5
10
15
20
25
30
35
40

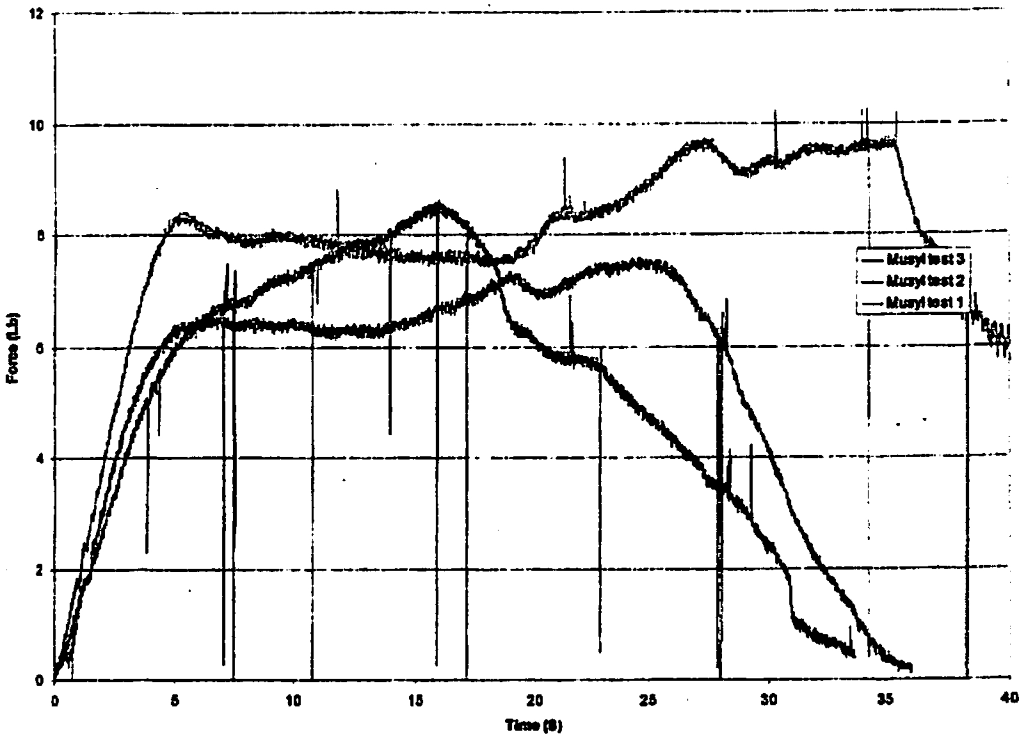

Force (Lb)
Time (S)
4 PMA test 10
4 PMA test 9
4 PMA test 8
4 PMA test 7
4 PMA test 6
4 PMA test 5
4 PMA test 4
4 PMA test 3
4 PMA test 2
4 PMA test 1

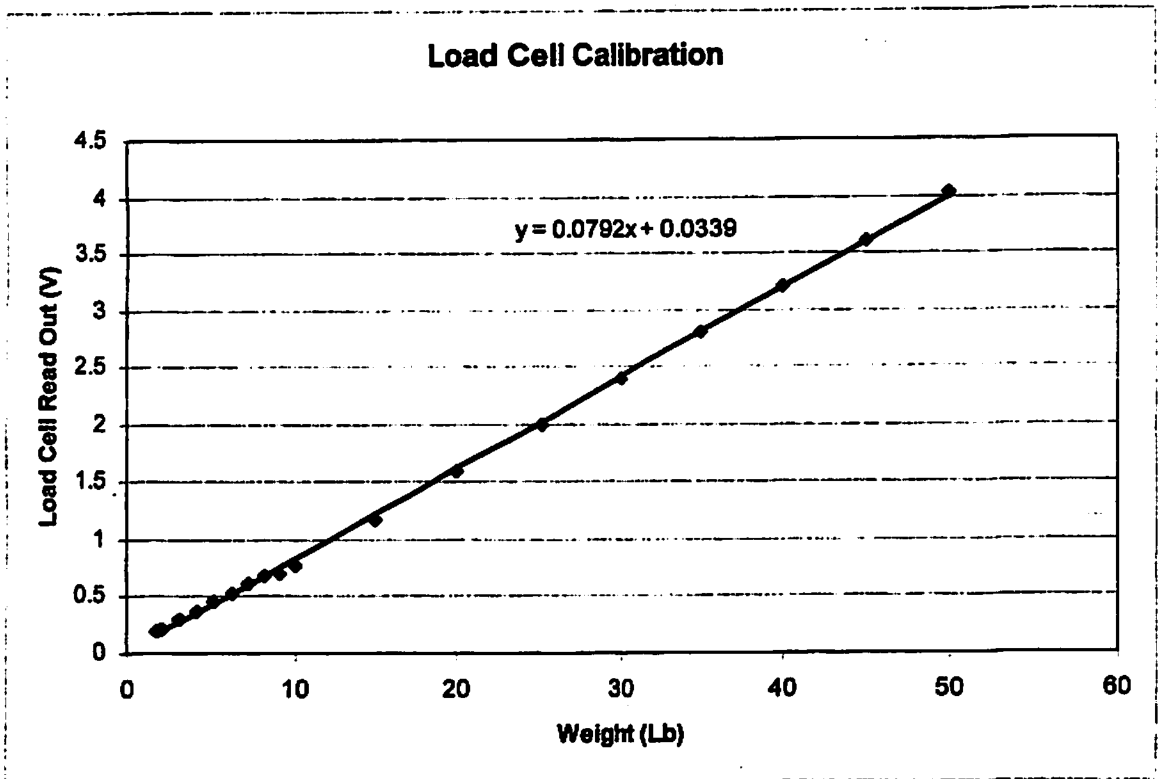
Musyl test 1

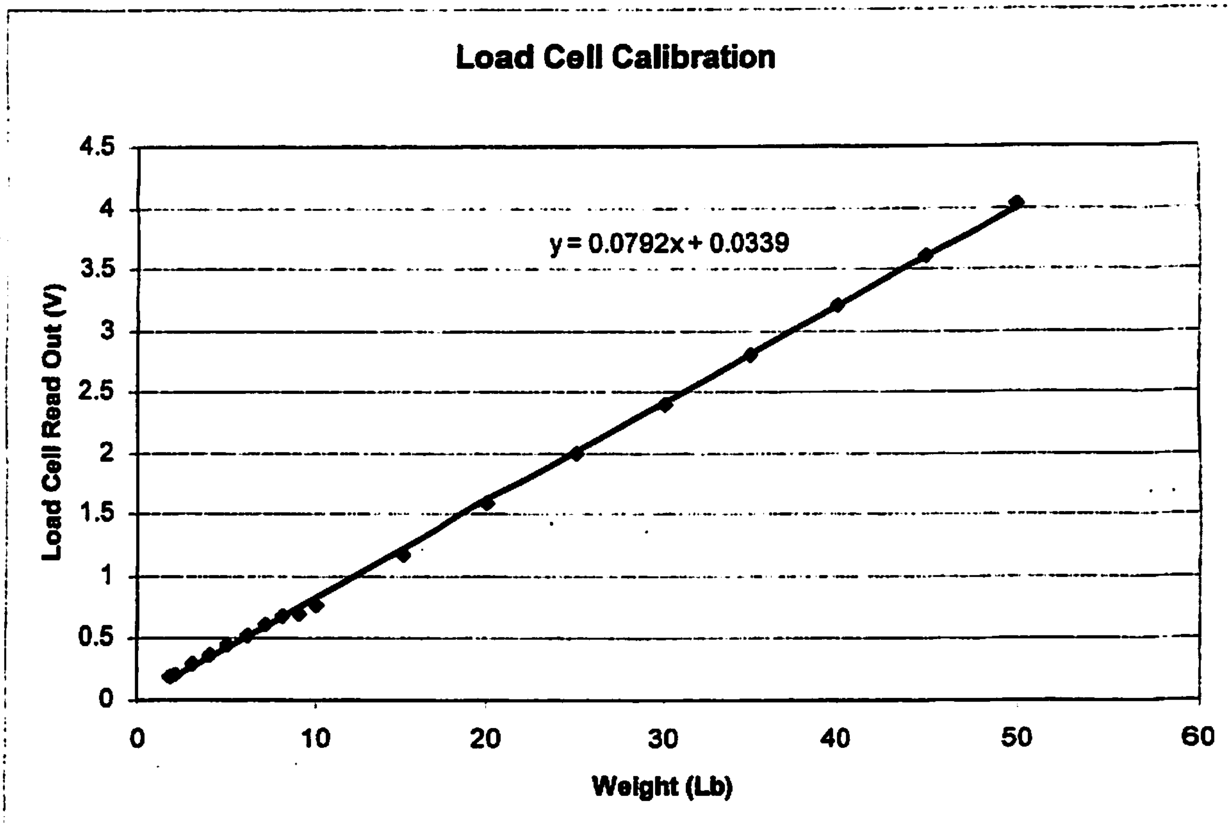


Musyl test 2

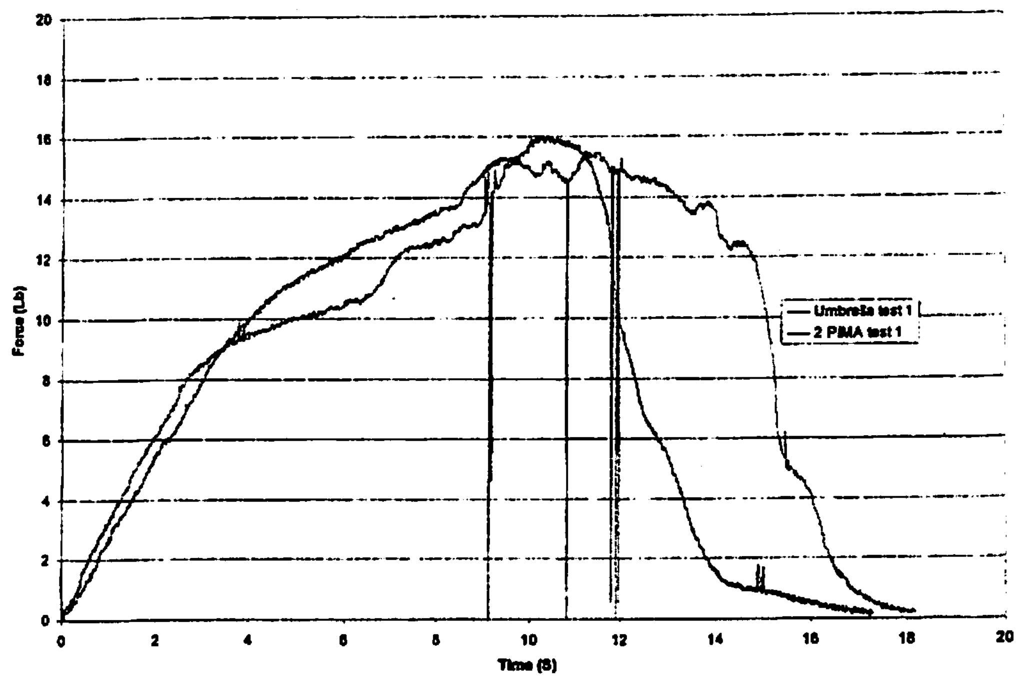



12
10
8
6
4
2
0
Force (Lb)
0
5
10
15
20
25
30
35
40
Time (S)
Musyl test 3
Musyl test 2
Musyl test 1

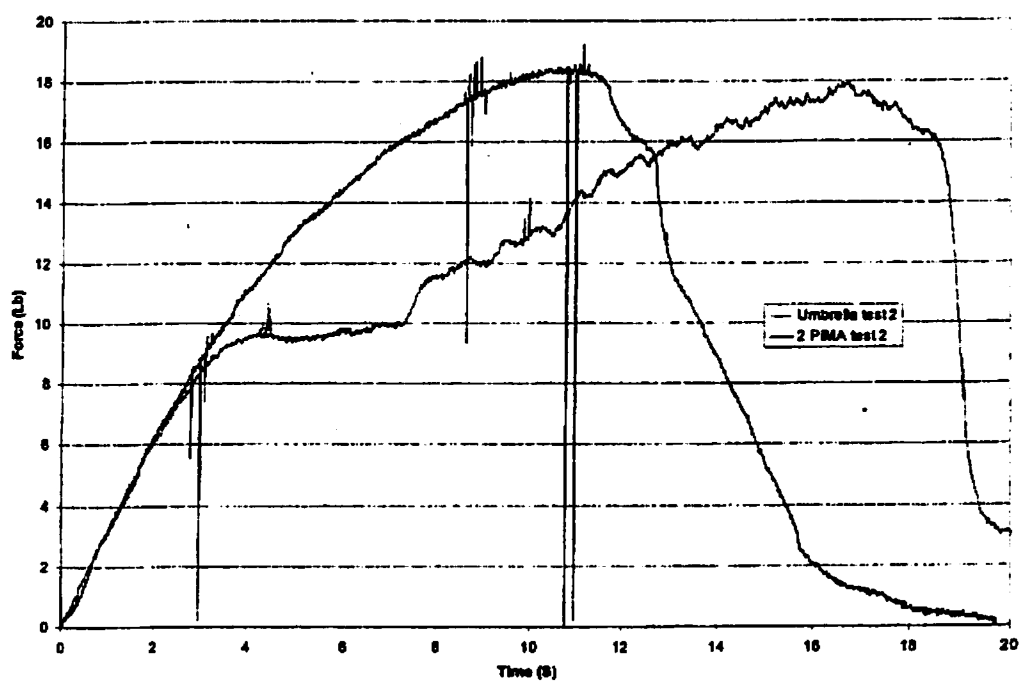

Load Cell Calibration
y = 0.0792x + 0.0339
Load Cell Read Out (V)
Weight (Lb)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
10
20
30
40
50
60


Load Cell Calibration
y = 0.0792x + 0.0339
Load Cell Read Out (V)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
0
10
20
30
40
50
60
Weight (Lb)

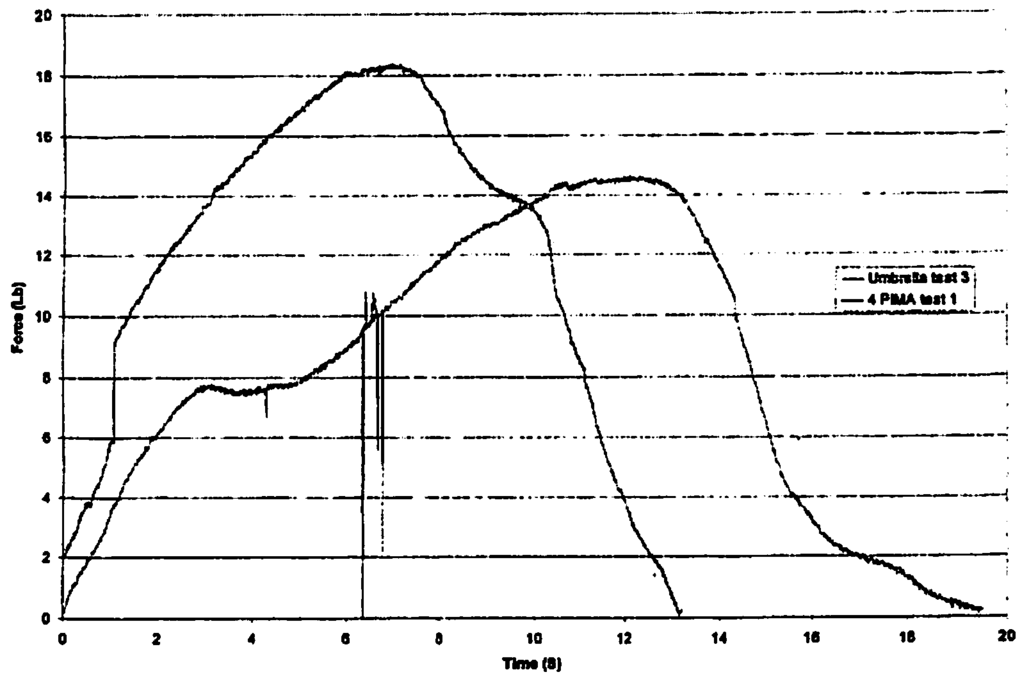
Container 1



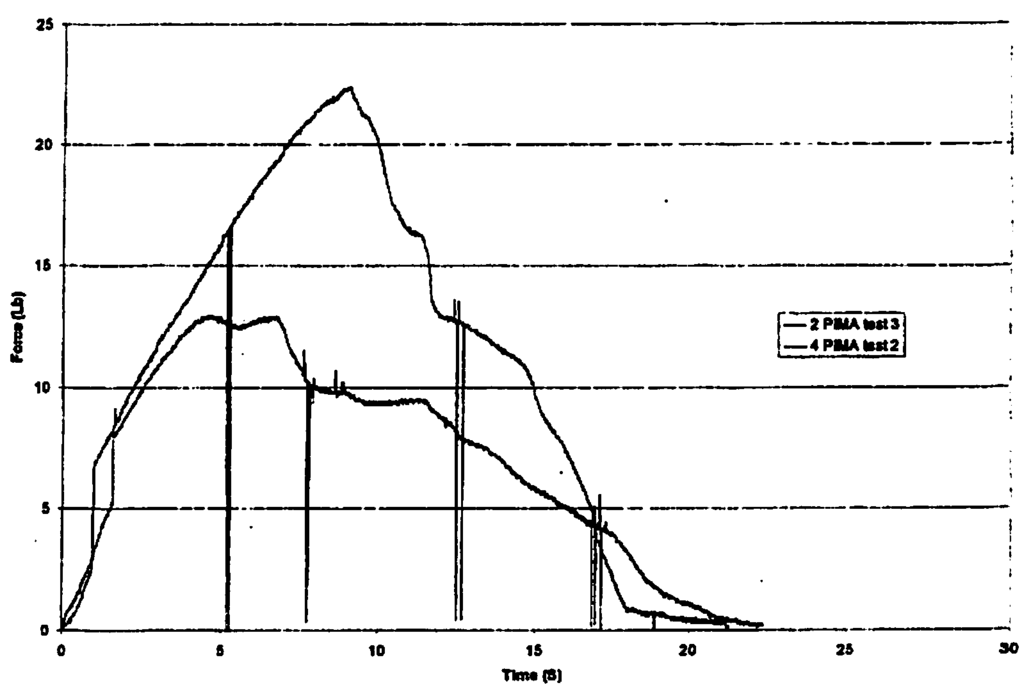
Container 2



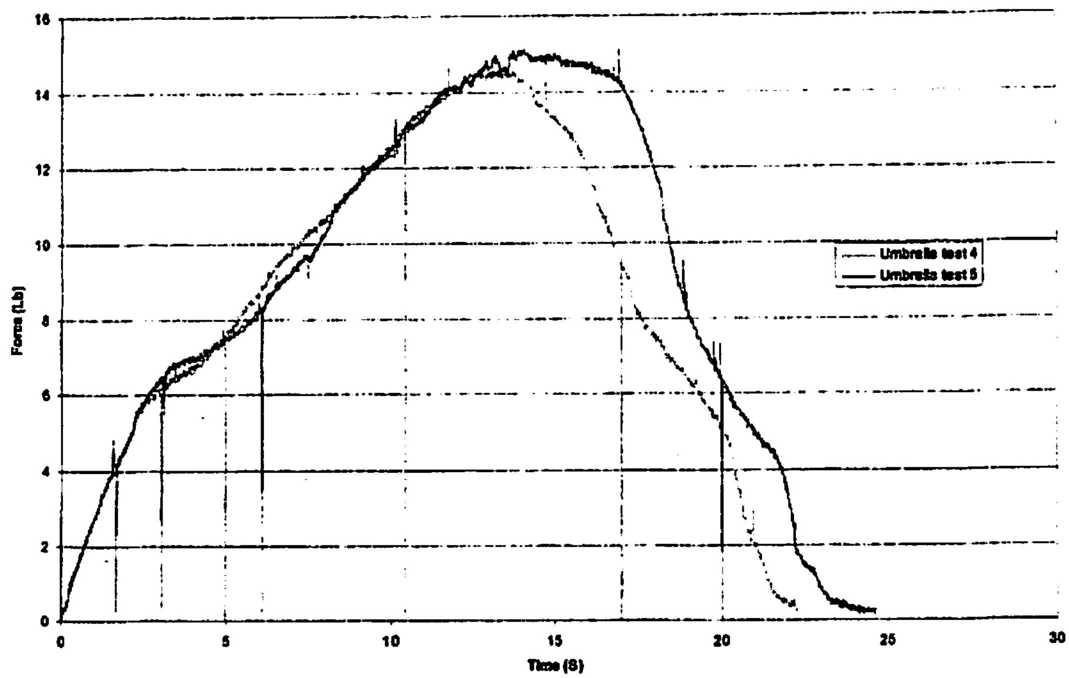
Container 3



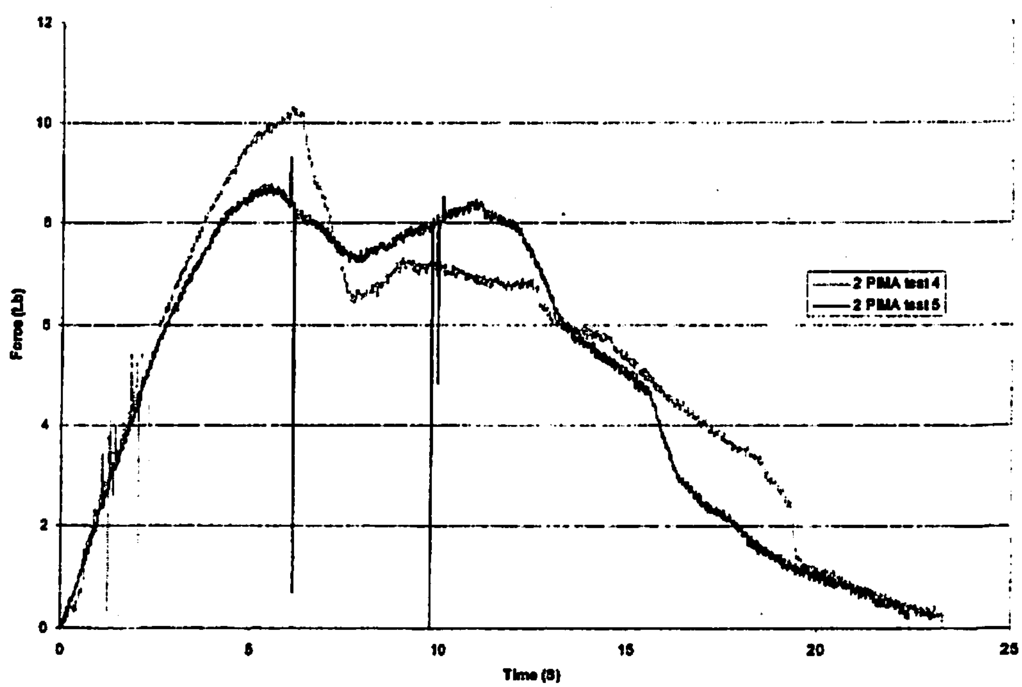
Container 4



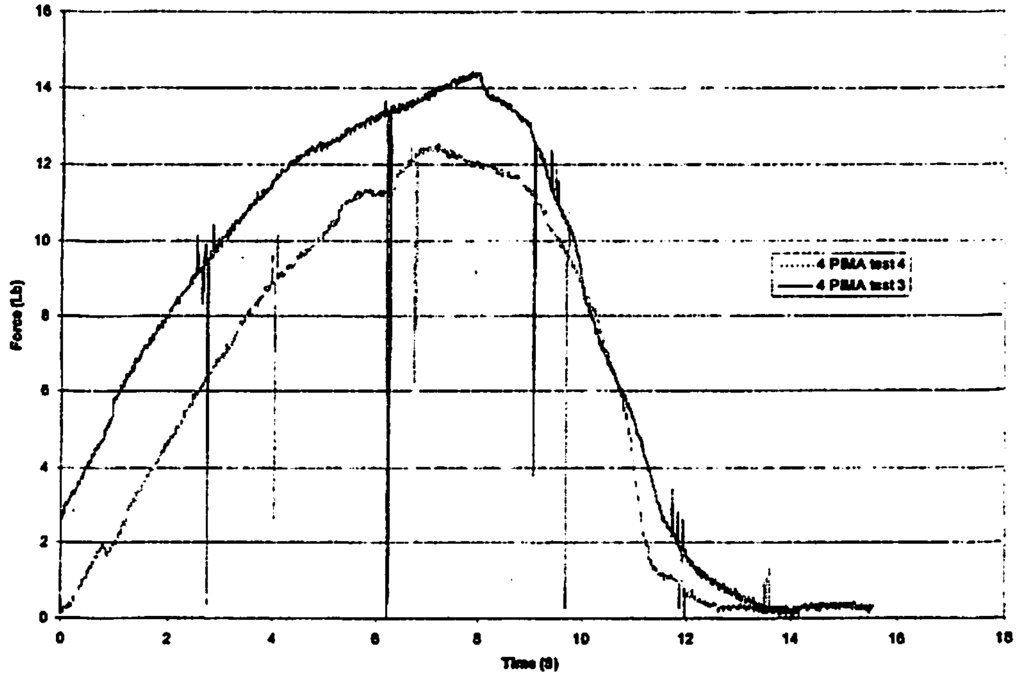
Container 6.1



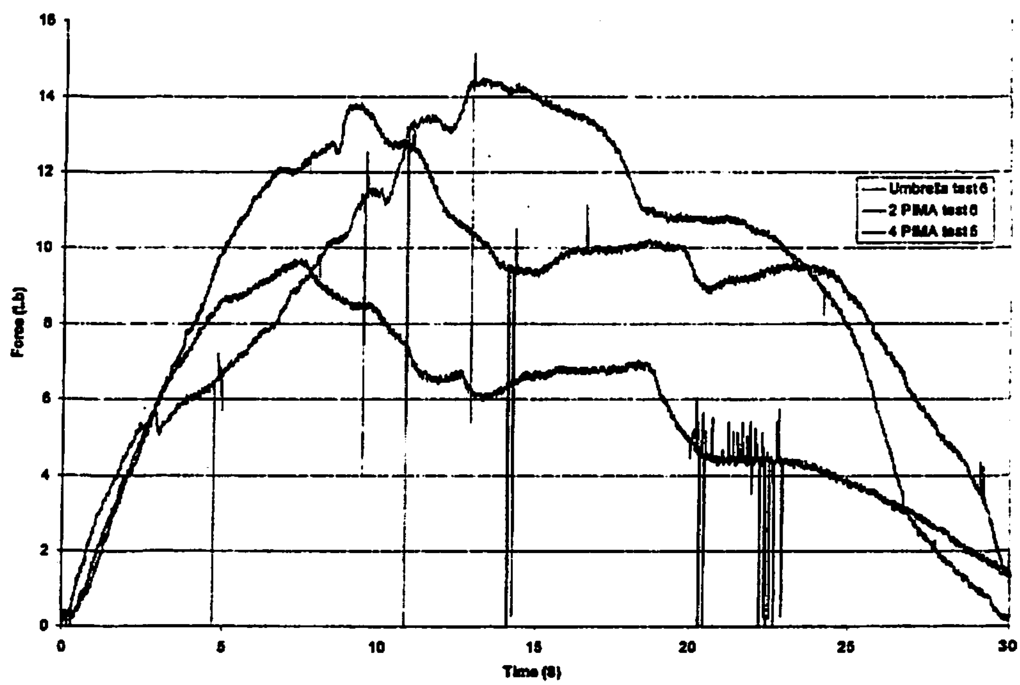
Container 6.1



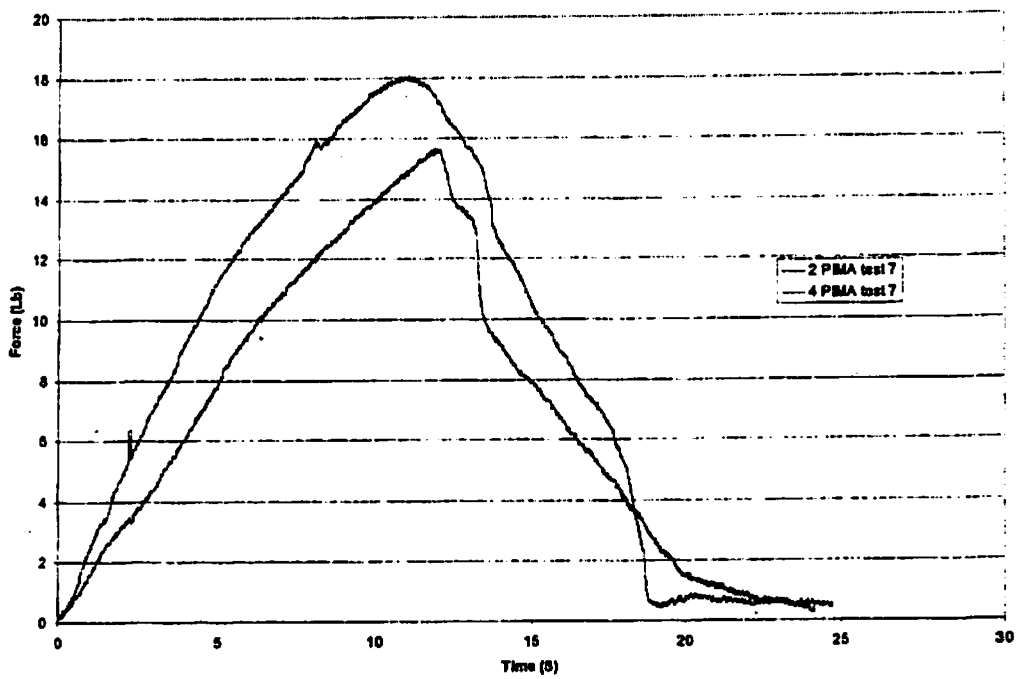
Container 7



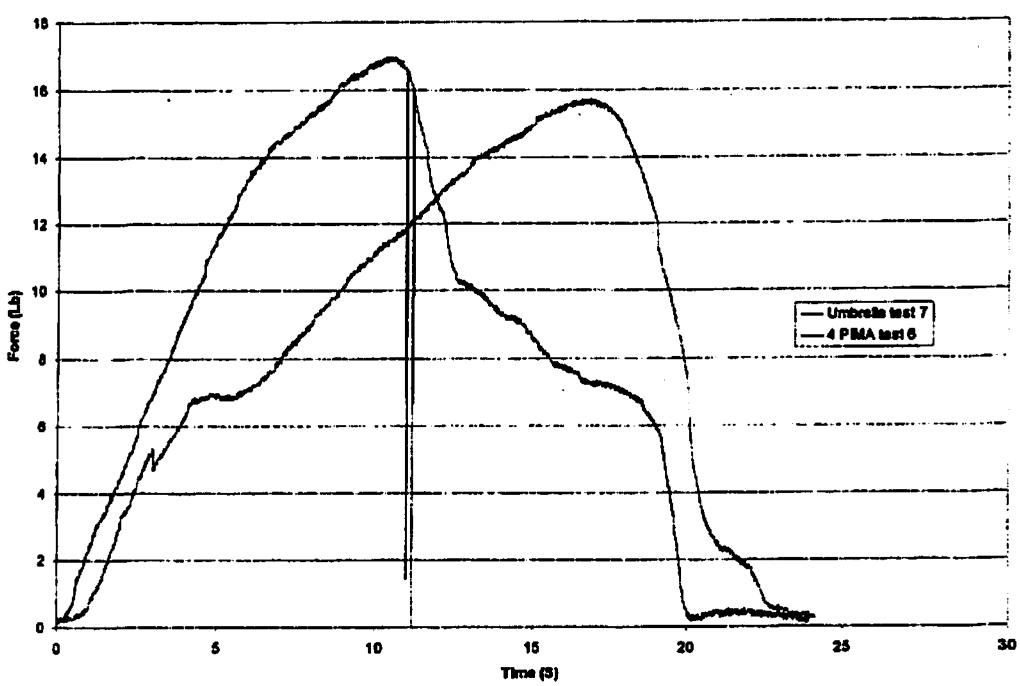
Container 8



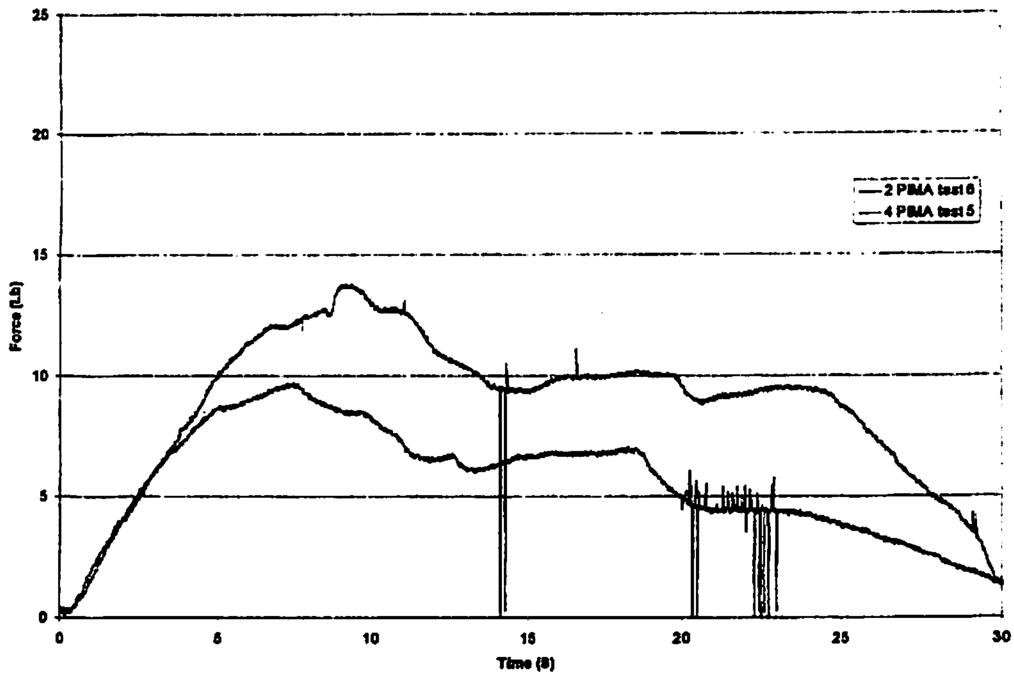
Container 5.2



Container 6.2



Container 8 mod



Appendix C