Research Institute
The University of Alabama in Huntsville

Technical Report 5-33567
Contract No. NAS8-38609
Delivery Order No. 119

Methods of Video and Shearography Inspection
(5-33567)

Final Technical Report for Period
22 September 1994 through 21 September 1995

September 1995

Prepared by

Matthew D. Lansing
Michael W. Bullock
William J. Gnacek

Research Institute
The University of Alabama in Huntsville
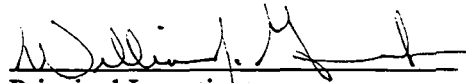Huntsville, Alabama 35899

Prepared for

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, AL 35812
Attn: EH13 (Dr. Samuel S. Russell)

PREFACE

This technical report was prepared by the staff of the Research Institute, The University of Alabama in Huntsville. The purpose of this report is to provide documentation of the work performed and results obtained under delivery order 119 of Marshall Space Flight Center (MSFC) Contract No. NAS8-38609. Mr. William J. Gnacek was Principal Investigator for this twelve month level of effort. Dr. Samuel S. Russell of the Nondestructive Evaluation Branch provided technical coordination.

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official NASA position, policy, or decision unless so designated by other official documentation.

I have reviewed this report, dated ___20 Sept 95___ and the report contains no classified information.

Principal Investigator

TABLE OF CONTENTS

1. INTRODUCTION

The Research Institute at the University of Alabama in Huntsville (UAH) was tasked by the Nondestructive Evaluation (NDE) Branch (EH-13) at Marshall Space Flight Center (MSFC) to study methods of video image correlation and electronic shearography for nondestructive evaluation. The purpose of this task was to study and develop methods and tests to evaluate the structural integrity of aerospace components using these techniques. Methods of physical load application must be developed before interrogations with these methods may be used to qualify hardware. To that end, inspection procedures were developed for a variety of aerospace components and material systems. Experiments were also conducted from which the relationship between the control settings of the electronic shearography apparatus may be related to flaw delectability. A short feasibility study was conducted to determine the applicability of electronic shearography to the determination of the stress intensity factor of a Mode I crack tip by measurement of the localized zone of three dimensional plasticity.

2. BACKGROUND AND OBJECTIVES

The NDE Branch at MSFC maintains a laboratory for the application and development of the methods of video image correlation and electronic shearography. This facility is equipped with a Pratt-Whitney Electronic Holography/Shearography Inspection System (PW EH/SIS) and a Laser Technology, Inc. (LTI) SC-4000. Electronic shearography techniques provide non-contact real-time location and sizing of defects in many material systems.

2.1. ELECTRONIC SHEAROGRAPHY

Electronic shearography images a coherently illuminated object through an image shearing lens to produce an interference fringe pattern[1-3,5-7,12,14, 22-23,25-26]. The boundaries between light and dark fringes represent contours of constant change in surface slope due to some form of excitation. The PW EH/SIS at the MSFC NDE Branch Electronic Shearography Laboratory was used to interrogate most of the specimens for this study. This device utilizes a modified Michelson interferometer as an image shearing device, as shown in Figure 1. A frequency doubled Nd:YAG pumped diode laser (λ = 532 nm) is used as a source of coherent illumination, the beam of which passes through a spatial filter and an etalon to produce a stable divergent speckle pattern on the surface of the test article. The light reflected from the object is collected by a telephoto lens, which provides a variable field of view, and imaged onto the sensor array of a CCD camera through the shearing interferometer.

Each ray passed through the telephoto lens is separated by the beam splitter into a reference beam and a sheared beam. The reference beam passes straight through the beam splitter, reflects from a phase stepping mirror back along its previous path, and is reflected from the back of the beam splitter toward the sensor array. The sheared beam is reflected from the front of the beam splitter toward the image shearing mirror, reflected back again at a tilted angle, then passed through the beam splitter toward the sensor array. The

sheared beam is incident on the sensor array at a point which is shifted, or sheared, from the reference beam. Each point on the surface of the object is thus imaged to two separate pixels on the camera sensor array. A more complicated reverse ray trace shows that, similarly, a single pixel on the camera sensor array images two sheared points on the surface of the object. Assuming a planar object, all points in the image are sheared by the same lateral distance, referred to as the image shearing distance, s. The sensitivity of the device is proportional to s and thus related to the angle at which the image shearing mirror is tilted. By varying the tilt angle and direction of the image shearing mirror, the operator may adjust the sensitivity of the device to suit the structure being evaluated and the type of excitation being applied.
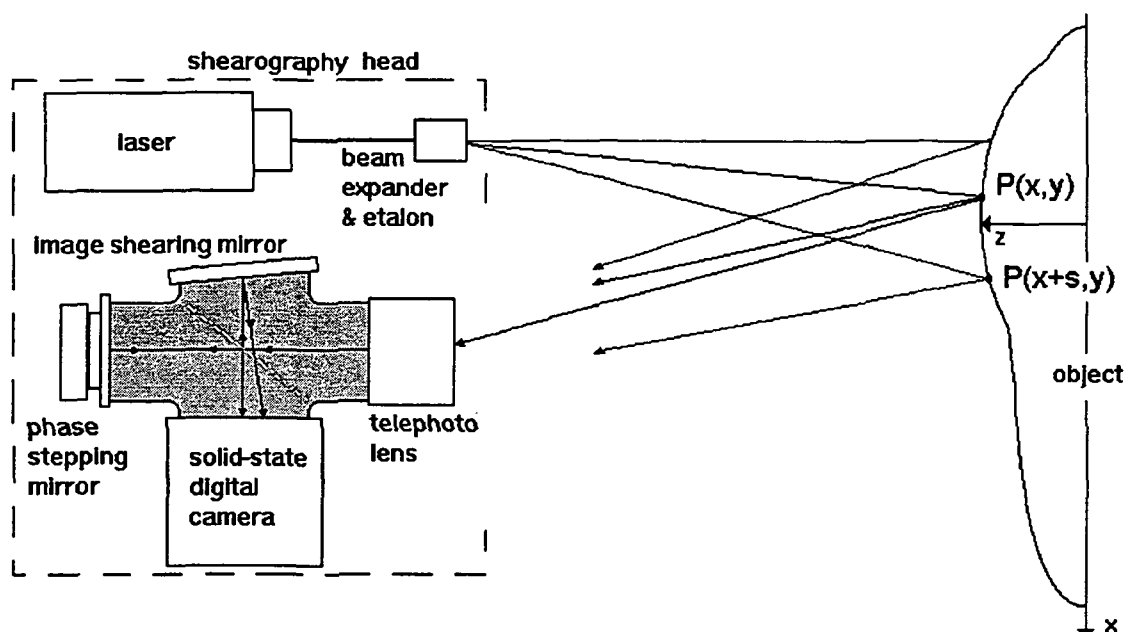
Figure 1. PW EH/SIS Optical Arrangement

Unlike electronic holography (EH), which produces fringe patterns indicative of object displacements toward the camera, ES senses changes in the slope of the surface of the object along intervals of the image shearing distance. That is, the fringes are produced by differences in motion toward (or away from) the camera between points separated by s. The ES technique is thus less sensitive overall than is EH. In addition, some EH techniques pass the reference beam directly from the laser to the sensor array inside an optical fiber and only the object beam reflects from the test article. Other EH techniques illuminate the test object with two coherent beams having almost entirely different optical paths in object space. The optical paths of the reference and sheared beam in ES differ only inside the interferometer. The ES technique is thus less sensitive to environmental effects (changes in vibration, temperature, etc.) than is EH. The ES apparatus does not require extensive environmental isolation, such as an optical air table, and is regularly used for field evaluations.

In the static test mode, sheared images are digitally acquired before and after some form of excitation is applied to the test article. The intensity recorded on each pixel is a

function of the relative phase between the light rays reflected from the two corresponding points separated by s in the direction of image shearing on the object surface, and thus a function of the relative slope across that interval of the image shearing distance. After the test object has been statically excited, typically by heating, cooling, or changing the pressure to which it is exposed, then a second sheared image is recorded. The digital frame subtraction of these two images results in a shearogram featuring a fringe pattern indicative of full-field values for the change in surface slope at each point on the object surface due to the excitation load.

2.2   SUB-PIXEL DIGITAL VIDEO IMAGE CORRELATION

Sub-pixel Digital Video Image Correlation[3,8-11,15-18,20-21,24] is a full-field non-contact computer vision technique for determination of in-plane displacements and strains in near-real-time. This technique utilizes readily available and inexpensive video equipment in conjunction with a Microsoft Windows environment image processing software package which is available from NASA COSMIC. Rather than qualitative fringe patterns, the results of SDVIC inspection are quantitatively scaled and indexed false-color plots indicating full-field values for both of the in-plane displacement components, both of the in-plane linear strain components, the in-plane shear strain, and in-plane rotations with sub-pixel resolution. A data file is also produced which contains the tabulated values for these measurements in a grid arrangement of points on the surface of interest. The separation distance and number of points for which data is tabulated is determined by the user.
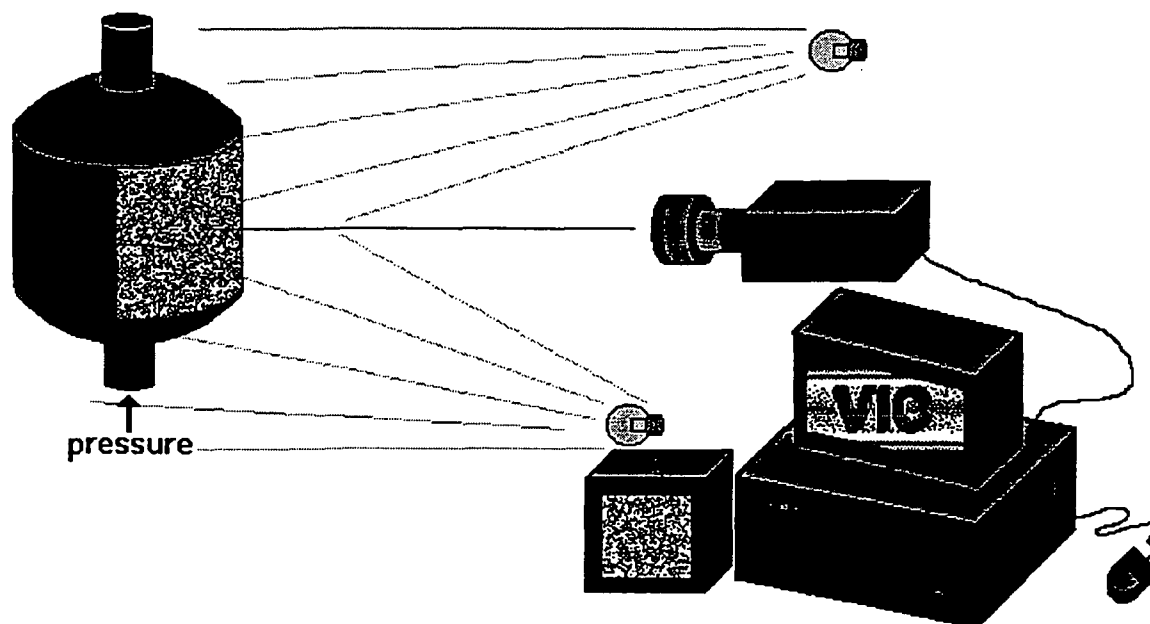
Figure 2.   Apparatus used for SDVIC data acquisition.

The apparatus used to acquire and process images for SDVIC is shown in Figure 2. with a domed cylindrical pressure vessel as an example specimen. The over-spray from

black and white spray paint is used to apply a random black and white speckle pattern to the surface of the specimen. This pattern is illuminated by a white light source and imaged by a Sony XC-77 CCD camera with a Sigma 70-210 mm telephoto lens. The video images are captured and digitized by a Data Translation DT-2862 frame grabber board in an Intel compatible personal computer.

3. DELTA CLIPPER-EXPERIMENTAL ADVANCED

The NASA Office of Space Access and Technology has entered into cooperative agreements with private industry to develop a Reusable Launch Vehicle (RLV) with the aim of lower manufacturing, maintenance, and launch costs than the current Space Transportation System (STS) Space Shuttle. One of the Single Stage to Orbit (SSTO) vehicles under development is the McDonnell-Douglas Delta Clipper. As an improvement upon the Air Force sponsored Delta Clipper-Experimental (DC-X) vehicle, the NASA sponsored DC-XA (DC-X Advanced) proposes to reduce lifted mass, and thus increase payload capacity and decrease launch expenses, by utilizing composite components not only in the load bearing structure but also in the propulsion systems. Electronic Shearography methods were developed for inspection of several of these components.

3.1. COMPOSITE FUEL TANK

The DC-XA will utilize Composite Overwrapped Filament Wound Pressure Vessels (CO-FWPV) to store liquid oxidizer (LOX) and liquid hydrogen (LH2) to fuel the vehicle propulsion systems. Tests were performed to explore the problem of hydrogen permeability in such structures. It was observed during helium pressurization tests of a subscale composite pressure vessel that delaminations on the dome section near an end boss caused considerable leakage. These delaminations were not visible to the unaided observer. The capability of Electronic Shearography for evaluation of such delaminations on the dome section of CO-FWPV has been demonstrated.

3.1.1. SPECIMEN

The Nondestructive Evaluation Branch (EH13) was provided a graphite-epoxy (Gr-Ep) CO-FWPV with delamination leaks near an end boss. This was a 5.75" diameter filament wound bottle, similar to ASTM standard D2585-68 (1985), with pre-preg Gr-Ep tape over-wrap. Figure 3. schematically illustrates the structure of the bottle.

3.1.2. PROCEDURE

The Pratt-Whitney Electronic Holography / Shearography Inspection System (PW EH/SIS) was used to evaluate the response of the bottle to
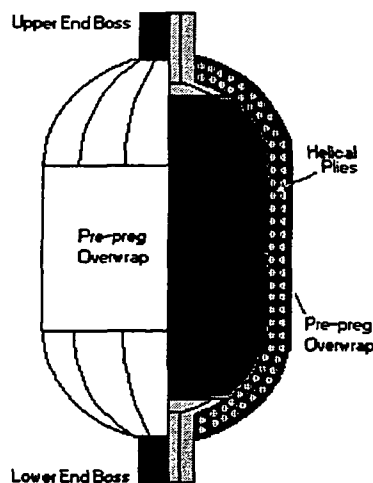
Figure 3. Specimen Geometry

thermal excitation. The image shearing distance was set to 1/8" horizontal at an object-to-lens distance of 4'. The telephoto lens was focused on the dome at maximum zoom with the optical axis of the camera approximately coincident with the longitudinal axis of the bottle. Static shearograms were obtained using speckle averaging and four frame averaging. No traveling fringes were displayed. A reference shearogram was obtained after the bottle had been slightly heated ($\Delta T < 5°F$) with an industrial heat gun. The deformed shearogram was taken after the bottle had cooled to approximately room temperature. The resulting interferogram is a superposition of these two images.

3.1.3 RESULTS

Electronic shearograms are interpreted by the light and dark fringe patterns they present. Each fringe represents a contour of change in surface slope produced by, in this case, thermal relaxation. Figure 2. is a shearogram of the end boss-dome section which did not leak. Away from the boss, the fringes are widely spaced and exhibit a smooth transition from dark to light. The pattern here is one of concentric parabolas. As the dome cools its radius of curvature changes. The positive slopes on the left decrease while the negative slopes on the right increase. Near the boss, the fringes are closer together, have sharper edges, and appear to be less regular. This is due to the local change in geometry (compared to the rest of the dome) and the interactive presence of the boss. However, the pattern of concentricity is still fairly evident.
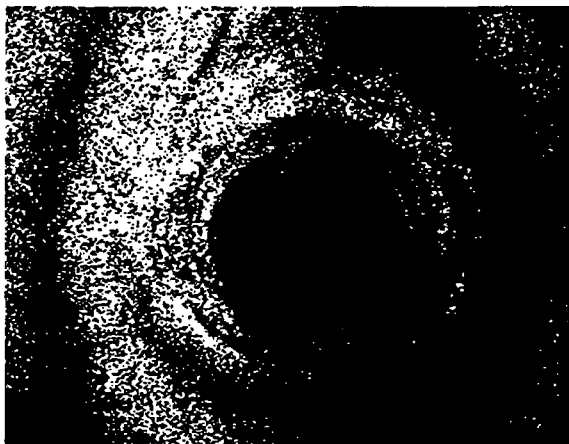
Figure 2. Sound Polar Boss

Figure 3. Leaking End Boss

Figure 3. is a shearogram of the end boss dome section which did leak. Identifying marks may be seen on the end of the boss. Away from this boss the fringe pattern is similar to that of the other end of the bottle. However, near to the boss the pattern becomes convoluted and irregular. This indicates a less directionally oriented and less uniform deformation pattern than would be expected of a sound lamination bond or was exhibited by the opposite dome section. Also, the fringes are sharper and more closely spaced, indicating more overall motion. Non-uniform deformation indications such as these tangled fringe patterns are typical of delamination indications in many composite materials.

3.1.4. SUMMARY

It has been demonstrated that, when inspected with electronic shearography, a leaking end boss in a composite overwrapped filament wound pressure vessel produces the same sort of fringe pattern discontinuity which is typical of a composite delamination. A sound end boss has been shown to produce a more regular and symmetrical pattern. The ability to distinguish a sound end boss from a leaking end boss indicates that electronic shearography is capable of assessing end boss delaminations without pressurizing the vessel.

3.2. COMPOSITE LIQUID HYDROGEN FEED LINE

In addition to the composite fuel tanks, the DC-XA will utilize composite feed lines for liquid hydrogen between the fuel tank and liquid-gas converter (LGC). The geometry of the flight article feed line is shown in Figure 4. The presence of delaminations in the composite components or bonded joints could lead to catastrophic vehicle loss. Throughout this development effort, specimens were provided to the MSFC NDE Branch for ES inspection to detect such delaminations. Thermal excitation was used for all inspections.

Figure 4. DCX-A composite liquid hydrogen feed line.

3.2.1. JOINT COMPONENTS

Prior to joint bonding, specimens representative of the composite lay-up were inspected with ES. The image shearing distance was adjusted to 0.04 inch at an object distance of 4 feet with the telephoto lens focused on the surface of the tube closest to the shearography device. A typical shearogram is shown in Figure 5. Possible resin-rich areas along the edges of the axially oriented pre-preg strips were indicated by axial linear dark fringes. Possible wrinkles in the lay-up were also indicated by rows of parallel dark fringes

skewed from the axial direction. Gaps or wrinkles in the lay-up could be expected to form these resin-rich regions during consolidation.
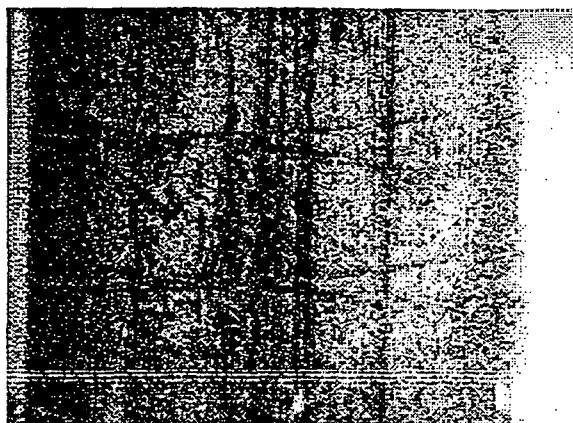
Figure 5. Indications detected along the edges of both axial and helical strips in the feed line splice section* .

Figure 6. (N) Detection of an internal delamination simulated by a Teflon insert and indicated by a double bull's-eye.

Another specimen representing a section of feed line tube with simulated delaminations was inspected with an image shearing distance of 1/8 inch horizontal and 1/8 inch vertical. The delaminations were simulated by pillows fabricated from Teflon tape which were heat sealed along all four sides and inserted into the lay-up. A similar inspection procedure detected the inserts as indicated by the typical "double bull's-eye" in Figure 6.

3.2.2. DEMONSTRATION TEST ARTICLE

A demonstration test article (DTA#1-2) was inspected for bond line integrity with ES. This test article differed in geometry from the flight article in that a flat titanium flange attached to a straight composite tube replaced the tapered titanium flange and angled composite tube. X-ray computed tomography (CT) had detected a large delaminated region along the bond line between the inner feed line sections and the sleeve around the joint. The result of ES inspection of this portion of the feed line is shown in Figure 7. The unbonded region, indicated by large, feathery black fringes, appears larger than was indicated by CT. Subsequent radiographic inspections indicated similar unbonds which were, again, smaller in size than indicated by ES. It is likely that during ES inspection parts of the flaw were excited which were not detected by the other techniques because without loading the flaw surfaces remained in contact with each other. This is often referred to as a "kissing" delamination, and is among the most difficult flaws to detect with many methods.

---

* This shearogram is shown as a negative image for clarity. Hereafter negative images will be noted (N).

Figure 7. (N) DTA#1-2, unbonded regions in the spliced joint with original bonding procedure.
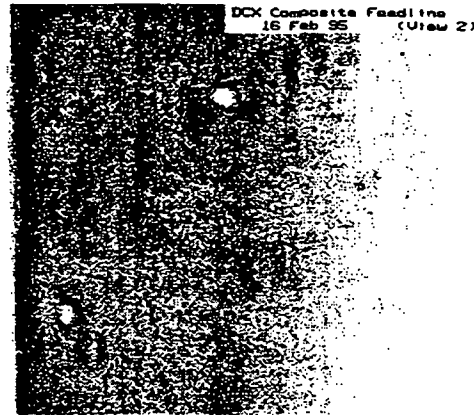
Figure 8. (N) DTA#1-2a, smaller unbonds detected with revised bonding, indications around epoxy injection holes.

### 3.2.3. DEMONSTRATION TEST ARTICLE WITH REVISED BONDING

A revised joint bonding procedure was developed to address the issue of the aforementioned unbonds. This procedure injects the epoxy between the inner feed line sections and the sleeve around the joint through 1/8 inch holes drilled in the sleeve. The sleeve was removed from the test article and replaced by another with the revised bonding procedure. The repaired part (DTA#1-2a) was inspected again with ES and no major indications were seen, as shown in Figure 8. Small circular indications were present at the epoxy injection holes, but the diameter of these indications were not significantly larger than the holes themselves, and the indications are believed to be the effect of a difference between the coefficient of thermal expansion of the feed line sleeve matrix and fiber and that of the joint bonding epoxy. The possibility exists that some machining damage was incurred during the drilling of the epoxy injection holes; however, such damage cannot be verified as there was no ES inspection prior to the bonding of the joint. Moreover, such machining damage may have been repaired to some degree by the injection of epoxy. The integrity of this repair cannot be verified because, again, no ES inspections of this type have been performed.

3.2.4. PROTOTYPE

A prototype feed line, identical in geometry and fabrication to the flight article, was inspected for bond line integrity similar to the preliminary test article. The results of this inspection are similar to that of the preliminary test article, with the same concerns about the epoxy injection holes. As shown in Figures 9. and 10., no major bond line delaminations were indicated. The injection holes appear as dark pairs of circles. The lay-up quality of the outer sleeve and inner feed line sections appears to have improved, as fewer minor anomalies were observed with an image shearing distance, and resulting sensitivity, up to four times that used for inspection of the demonstration test articles.
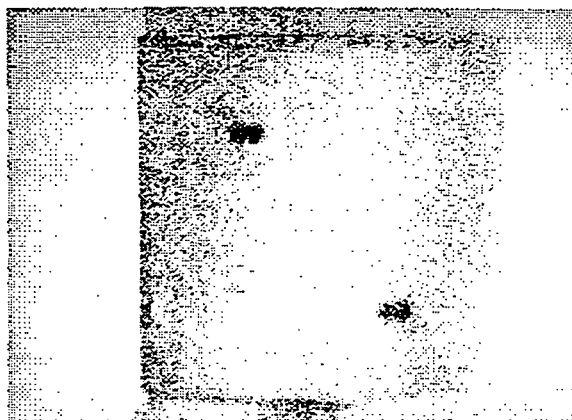
Figure 9. (N) Prototype, no unbonds detected in 90° to composite flange joint.
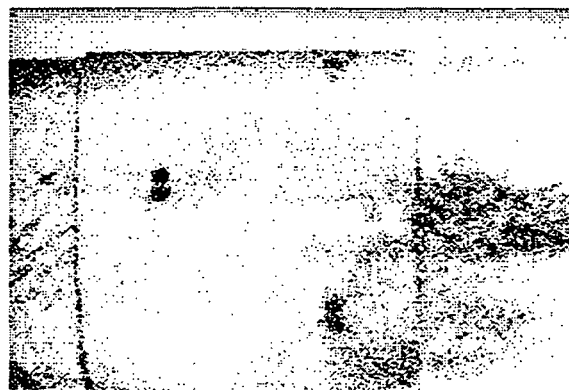
Figure 10. (N) Prototype, no unbonds detected in 90° to 45° bonded joint.

3.2.5. FLIGHT ARTICLE

Inspection of the flight article feed line assembly demonstrated that the bonded joints were of poorer quality than the prototype. As shown in Figures 11. and 12., respectively with and without indication labels, numerous small double bull's-eye indications appeared as well as an irregular vertical fringe pattern. The former indications are suspected to be small unbonds between the inner and outer tubes of the splice and the latter indication is suspected to be the influence of these small flaws on the surrounding material. However, the flight article was judged to be acceptable based upon the small size of the unbond indications.

Figure 11. (N) Numerous small unbonds detected in spliced joints of flight article produce complex fringe patterns.
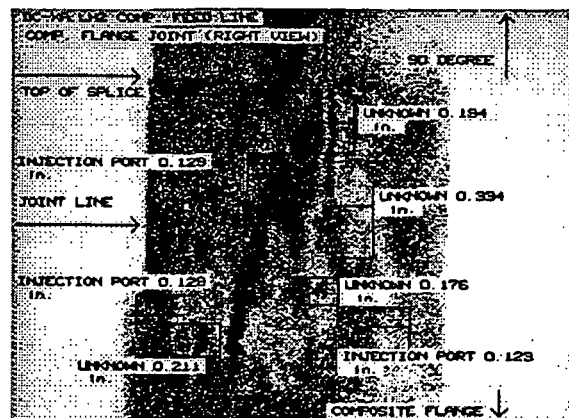
Figure 12. (N) Flight article unbonds, labeled here as UNKNOWN, judged to be acceptable based on small size.

3.3. COMPOSITE INTERTANK HONEYCOMB

The DC-XA composite intertank is being fabricated from an aluminum honeycomb with composite laminated inner and outer faces. This will provide significant weight reduction as compared to the current metallic structure. Areas of concern are the

presence of delaminations within the composite facing material, unbonds between the facing and the honeycomb core, and impact damage which may result in both types of delaminations as well as crushing of the honeycomb.

A specimen typical of the composite honeycomb with laminar facing for the DC-XA intertank was inspected with electronic shearography to determine the detectability of programmed impact damage. The specimen was cut from a larger coupon which had been impacted several times. This section contained two labeled impact points. A razor blade was used to separate the laminated plies in one corner to simulate a delamination in the facing material. Similarly, the facing material was unbonded from the honeycomb on one corner and in the middle of a free edge.

Figure 13. clearly indicates the location of the two impact points as a pair of large double bull's-eye fringe patterns. Several smaller double bull's-eye indications appear and are suspected to be damage caused by the c-clamps used to hold the specimen during impact. Figures 14. and 15. demonstrate the detection of delaminations between the laminant plies, between the facing and the honeycomb, and of unknown origin.

Figure 13. (N) Impact damage to intertank coupon indicated by 2 large double bull's-eyes. Other damage indicated by numerous smaller double bull's-eyes.
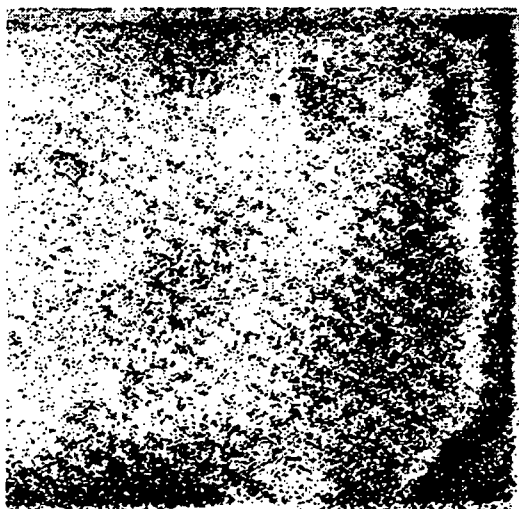
Figure 14. (N) Composite skin delamination (upper right) and skin to honeycomb (lower right) delaminations.
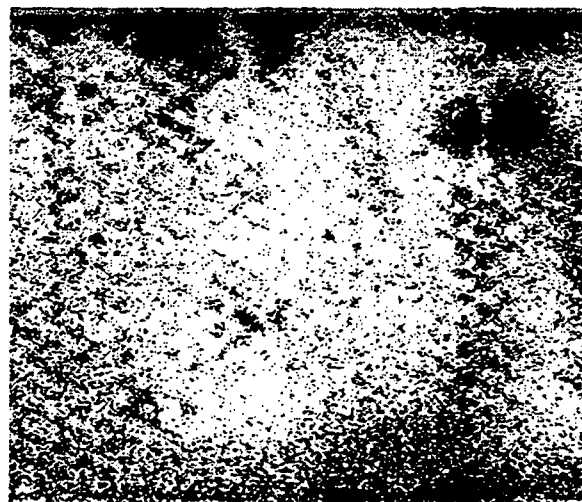
Figure 15. (N) Skin to honeycomb delamination (upper left) and unknown double bull's-eye (upper right).

4. IMPACT DAMAGED FILAMENT WOUND PRESSURE VESSELS

Composite pressure vessels are being used with increased frequency for aerospace and other applications. The DC-XA, discussed in the previous section, will utilize filament wound pressure vessels (FWPV) to store liquid oxidizer (LOX) and liquid hydrogen (LH2) to fuel propulsion systems. The Transfer Orbital Stage (TOS) satellite boosters are solid rocket motors with filament wound cases. The possibility exists that during handling or service these composite structures may suffer impact damage. This damage may be in the form of highly localized fiber breaks and matrix cracking, more widespread internal delaminations, or some combination of the two. The nature of the impact damage is determined by the material system and the geometry and energy of the impactor.

Historically the complex material systems which give composite structures their desirable qualities have at the same time complicated the task of inspections for structural integrity. The hard x-rays typically used for radiography of metallic structures tend to wash out features which would otherwise indicate damage. The presence of solid rocket fuel in a composite case results in an inverse problem in that the filler material properties and thickness render it almost opaque to these x-rays. Likewise, the eddy-current techniques which are regularly used to locate and size cracks in metallic structures are ineffective for non-metallic composites. In many cases, a load or pressure proof test above that expected in service and perhaps as high as 90% of expected ultimate is used where other nondestructive evaluation (NDE) techniques are unavailable. These proof tests are expensive, potentially dangerous, and most likely induce damage which weakens the structure. If nothing else, then such a proof test is yet another high load fatigue cycle which shortens the service life of the structure.

This study demonstrates the complimentary abilities of two computer vision techniques to characterize the nature and extent of impact damage in filament wound pressure vessels with a single thermal cycle of less than five degrees Fahrenheit and a proof cycle of less than 25% of expected ultimate load. Electronic shearography (ES) and Sub-pixel Digital Video Image Correlation (SDVIC) are used to evaluate the structural integrity of these specimens with respect to internal delaminations, fiber breakage, and matrix cracking. ES is a variation of traditional holography which allows computer sensing of changes in surface slope components of the specimen due to some form of excitation. SDVIC is based upon the much older scribed grid technique for strain measurement and allows full-field non-contact measurement of in plane displacements and strains. ES and SDVIC results are shown to correlate well with the impact state and lowered burst pressures of these damaged vessels.

4.1 SPECIMEN

The FWPV evaluated here conformed to ASTM standard D2585-68 (1985) and were fabricated by Thiokol Corporation at the Marshall Space Flight Center (MSFC) Productivity Enhancement Complex. The bottles were formed as shown in Figures 16. and 17. by a series of filament wound helical and hoop plies, with the outermost in the

cylindrical region being oriented in the hoop direction. Both ends of the bottle terminated in metallic polar bosses allowing access to the internal cavity.

Impact damages ranging from unapparent to the unaided observer to obvious indentions or partial perforations were produced in the FWPV by means of a calibrated dead weight drop fixture. Impact of the specimens was performed by the MSFC Polymers and Composites Branch. The impact energies used for this study were determined by preliminary testing. Micrographs of specimens impacted at various energies indicated the type of damage caused by each, and energies were thus chosen for this study which would produce significant damage as to effect burst pressures. All of these bottles contained a rubber liner to contain the pressurizing water after failure of the composite cylinder.

4.1.1. GRAPHITE-EPOXY

The population spanned three epoxy resins and various levels of impact. All test articles were manufactured with continuous Hercules IM-7 graphite fiber pre-preg. One third of the FWPV were bound with each of the toughened epoxies ICI Fiberite 977-2 and Hercules X8553-45. The final one third contained the untoughened Hercules 3501-6 ATL epoxy resin.

4.1.1.1.   EMPTY Gr-Ep CASES

Three bottles from each resin class were impacted with a 1/2 inch diameter tip at 3.5 ft-lb. (low), 5.0 ft-lb. (medium), and 7.0 ft-lb. (high) respective energies. One vessel from each resin class was left undamaged as a reference. The geometry of these specimen is shown in Figure 16.
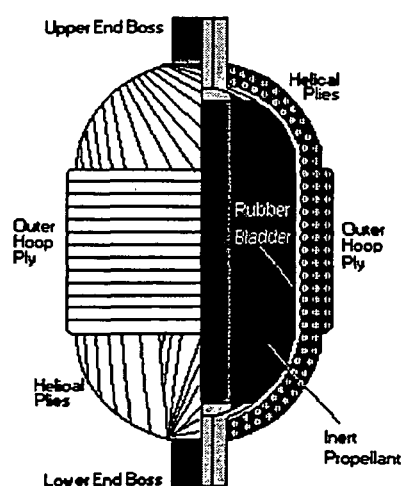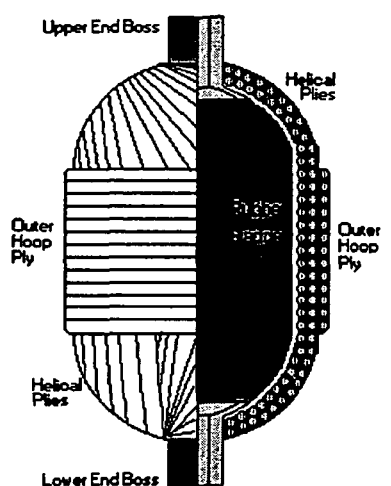

Figure 16. Geometry of empty specimens.   **Figure 17.** Geometry of filled specimens.

4.1.1.2.   Gr-Ep CASES FILLED WITH INERT PROPELLANT

All of these bottles were filled with an inert simulated solid propellant leaving an internal cavity approximately one inch in diameter running the entire axial length, as shown in Figure 17. This inert propellant was cast into the bottles and the internal cavity was then drilled out. The material was rubber-like and behaved mechanically similar to a pencil eraser.

4.1.2 KEVLAR-EPOXY

The kevlar-epoxy (K-Ep) FWPV evaluated here were manufactured in the same manner as the Gr-Ep bottles. The higher fracture toughness of the kevlar fibers as compared to that of the graphite fibers. Again, half of the population was unfilled and half was filled with the inert simulated propellant.

4.2. PROCEDURES

4.2.1. ELECTRONIC SHEAROGRAPHY INSPECTION

The majority of the ES inspections performed on these FWPV were performed with thermal excitation. This method was chosen for its ease and speed. A single vacuum excitation inspection was performed to demonstrate that the method was feasible, although more complicated and time consuming. Attempts to perform ES inspections during internal pressurization proved to be prohibitively difficult, but the method is discussed below.

4.2.1.1.   THERMAL EXCITATION

For this study, shearograms were obtained of each specimen after impact and prior to hydro-burst testing. The test articles were heated to surface temperatures slightly above ambient by thermal convection using an industrial heat gun. The heated specimens felt only slightly warm to the touch, and thus were minimally, if at all, harmed by the thermal cycle. Reference images were obtained while the FWPV were slightly warmer than ambient and these were digitally processed with later images at lower temperatures. The temperature differential between the two images was due to ambient cooling. The detected deformations are the result of thermal relaxation during this cooling.

The sensitivity of the ES apparatus was adjusted for these inspections such that the background motion of the structurally sound regions would lie within the first dark fringe The greater motion of any damaged region would appear within a first light fringe and perhaps higher order dark and light fringes. Preliminary testing determined that an image shearing distance of 0.25 inches with a field of view approximately 6 inches wide at a lens-to-object distance of 8 feet provided the desired sensitivity. Upon the application of heat, delaminated regions expanded without the constraint of being bonded to the underlying laminae. The structurally sound regions, however, were subject to this constraint and deformed more uniformly with lower magnitudes. The surface above the delaminated

regions thus behaved like a buckling plate, and it is this deformation which appears in the shearogram.

This type of damage and indication is typical of what was observed in the shearograms of the blunt tip impacts. All of these shearograms are included in appendix A.2., and a few examples are discussed in section 4.3.1. While visible surface damage in almost every case was minimal, if existent at all, the results of ES inspection consistently reveal fairly large "rose-petal" or "butterfly" type indications. Indications with these appearances are respectively typical of non-uniform delaminations in laminar composites where the delamination meanders among the plies and delaminations which are more uniform, effecting a small number of plies. The blunt tip impacts at low energy were manifested as somewhat circular indications having a diameter of 2 to 3 inches. The blunt tip impacts at high energy, however, appear to be symmetrical only in the hoop and axial directions. The width of the indications appear to be similar in the hoop direction, but they extend almost completely across the outer hoops in the axial direction.

The overall appearance of the ES indications suggests that, at the impact energies used in this experiment, the damage caused by the blunt tip impacts were primarily delaminations. The geometry (size and shape) of the indications suggest that the higher energy impacts generally resulted in delaminations which were larger in area and thus effected a greater number of the outer hoop fibers.

Alternatively, the impact may have caused a more localized region of fiber breakage and matrix crushing rather than having generated delaminations. In this latter case, some of the damage would be visible to the unaided observer, but the question remains as to how far the damage extends beyond that which is visible. The region weakened by micro-cracking around the impact could be similarly expected to be somewhat less constrained than the undamaged regions away from the impact, and thus expand and deform more due to the application of heat and be detectable by ES interrogation.

This appears to be the case with the sharp tipped impacts in this study. Most of these test articles featured visible crush zones where the impact tip actually severed fibers in the outermost plies and indented into the bottle. In none of these specimens did the indention visibly penetrate through to the rubber liner. The ES indications for the sharp tipped impacts are far more localized, and appear primarily as small double bull's-eye fringes. This type of indication is typical of a more uniform single-ply delamination than that observed with the blunt tip impacts. The indications for these bottles were in almost every case significantly larger than the 2 mm impact tip which resulted in the 2 mm visible indentions, and larger for the high energy impacts than those at low energy. ES inspection of a visible impact damage sight can thus determine how far the damage effected region extends beyond what is visible.

4.2.1.2. PRESSURE EXCITATION

4.2.1.2.1. INTERNAL VACUUM

A small vacuum pump was connected to the burst testing apparatus in place of the water pump. An internal vacuum of approximately 5 psig was pulled between reference

and subsequent images. Alternatively, the pressure was reduced prior to the reference image and restored before subsequent images. The image shearing distance, field of view, and object distance were adjusted to the same values used with thermal excitation. As illustrated in Figures 18. and 19., the delaminations in the test article were clearly evident.

Figure 18. (N) Vacuum application..
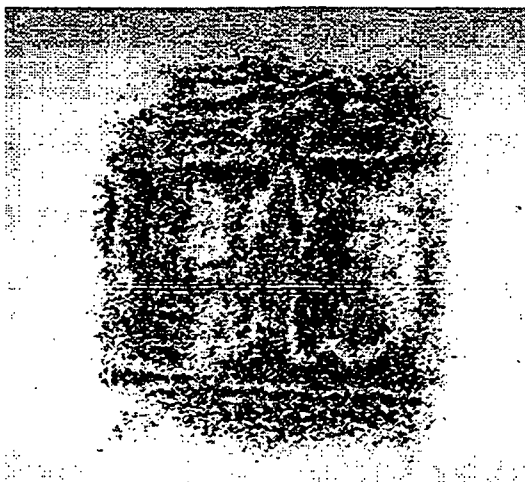
Figure 19. (N) Vacuum removal.

4.2.1.2.2.   INTERNAL PRESSURIZATION

An attempt was made to perform ES inspections while the FWPV were internally pressurized with the air driven water pump of the burst test apparatus. It was intended that while at house pressure (0 psig) or after the internal pressure had been increased to 250, 500, 750, or 1000 psig the manually controlled air regulator would gradually be adjusted to increase the pressure a few psig between reference and subsequent images. The problems faced included that adjusting the air regulator caused the water pump to cycle unpredictably, forcing a 100 psig jump in pressure, and that the ±25 psig fluctuations in the house water supply did not provide a stable reference. The low resolution with which the pressure could be controlled prevented any meaningful shearograms from being obtained.

4.2.2.   VIDEO IMAGE CORRELATION INSPECTION

The SDVIC images were acquired during a proof test with a maximum pressure of approximately 25% of the manufacturer's predicted burst pressure (approximately 4000 psi) for an undamaged FWPV of this geometry and manufacturing technique and these material systems. A typical pressurization schedule is shown in Figure 20. Digital images were stored after the initial 800 psig proof at 250 psig intervals from 0 to 1000 psig. Following this second pressurization cycle, each bottle was pressurized to burst. This pressurization schedule was used for all cases except the empty Gr-Ep FWPV, for which the second pressurization schedule excluded holds and data acquisition at 250, 500, and 750 psig. All pressure ramps were at approximately 10 psig per second.

These stored images were later correlated by the SDVIC software in a Microsoft Windows environment. The image processing software calculates a correlation integral between a pixel subset of the undeformed image and an interpolated gray scale function which is fit to a subset of the deformed image. This correlation factor, the result of the correlation integral, is minimized by a Newton-Raphson routine to determine the displacements,

Figure 20. Typical Pressurization Schedule for Hydro-proof of FWPV (maximum pressure approximately 25% of expected burst for undamaged specimen.

strains, and rotations which result in the best match between the undeformed subset and the interpolated deformed subset. The interpolation of the gray levels for the deformed subset allows deformation values to be determined with sub-pixel resolution. The software repeats this process, stepping across and down the undeformed image until results are determined for the entire field of interest with the desired resolution. The resulting deformation values may then be displayed as a scaled and indexed false-color plot. For this study, correlations were performed for each FWPV using the image taken at 0 psig prior to the pressurization cycle as the undeformed image. This image was then correlated with each of the images taken at each 250 psig incremental hold in the pressurization cycle. This process resulted in full-field hoop strain measurements from 0 psig to 250, 500, 750, and 1000 psig for the impact region of each bottle.

For the filled Gr-Ep and some of the K-Ep FWPV, in the interest of time, an initial low resolution correlation was performed for each load step with each FWPV over an area approximately 3 inches square. Impact damage was coarsely indicated as a subset or group of subsets with an anomalously large hoop strain as compared with the rest of the field. This initial correlation served to locate the impact zone. A second high resolution correlation was then performed over an area approximately 1 inch square. This second correlation more precisely indicated the geometry of the damage effected region and the strain values which occurred therein.

4.3. RESULTS

The results of ES and SDVIC inspections for all specimens in this study appear in appendix A.2. Shearograms and SDVIC hoop strain fields are tabulated for each class of specimen and ordered by impact state in each respective section.

4.3.1. EXAMPLES

The generalized results discussed here in detail correspond to the filled Gr-Ep FWPV. SDVIC results for the empty Gr-Ep specimens are similar, and ES inspections were not performed for these specimen as part of this study. ES results for the K-Ep FWPV, as shown in the appendix, indicate more extensive delaminations. This
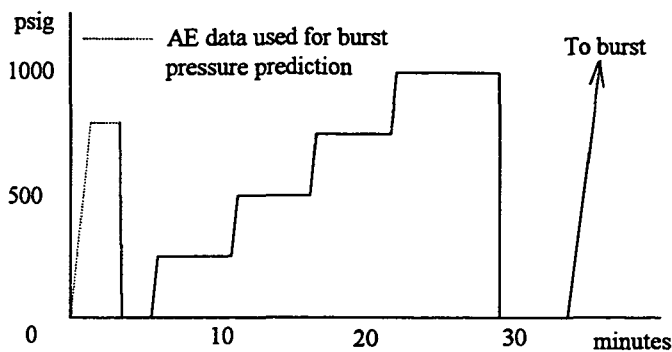
delamination and the generally featureless SDVIC hoop strain fields are due to the greater fracture toughness of the kevlar fibers as compared to graphite.

As indicated by ES interrogations, the damage caused by blunt tip impacts was primarily delamination. The large field area of the initial correlation approximately circumscribed the area indicated as delaminated by ES for low energy impacts with the blunt tip impactor. However, the smaller field area of the second correlation generally lay within the ES delamination indications. In either case, the delaminations did not act as stress concentrators in the plane of the surface of the bottle, and thus are difficult to distinguish in the hoop strain fields determined from either correlation. In some cases, however, there was sufficient damage caused by the blunt tip impact that some fiber breakage and matrix cracking occurred, if not upon impact then during pressurization, as illustrated in Figure 23.a. The indicated damage is a concentrated strain region as high as 2% at 1000 psig. Failure at elevated pressure originated at this point.
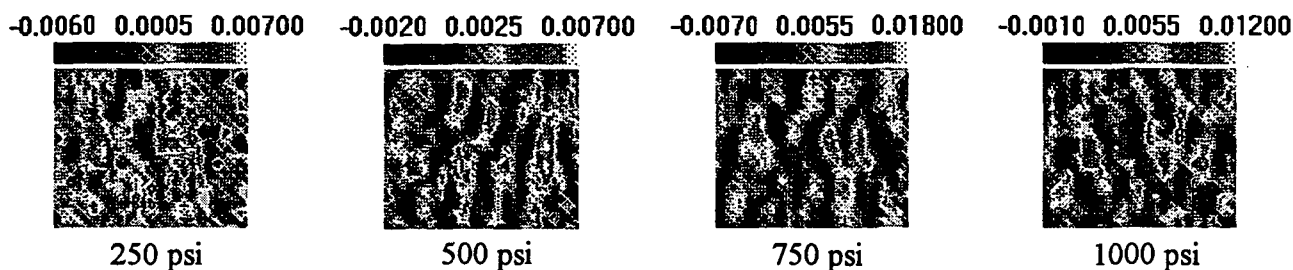
-0.0060 0.0005 0.00700   -0.0020 0.0025 0.00700   -0.0070 0.0055 0.01800   -0.0010 0.0055 0.01200

250 psi   500 psi   750 psi   1000 psi

Figure 21.a. SDVIC Hoop Strain Measurements for No Impact
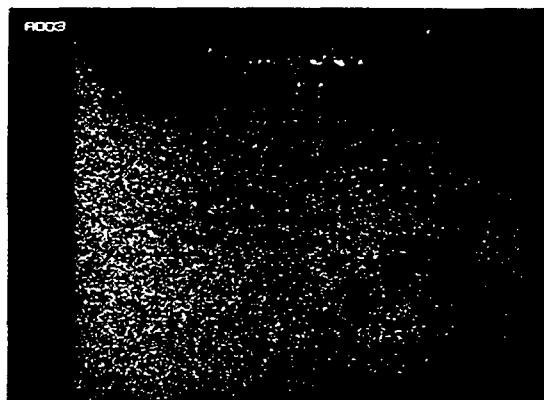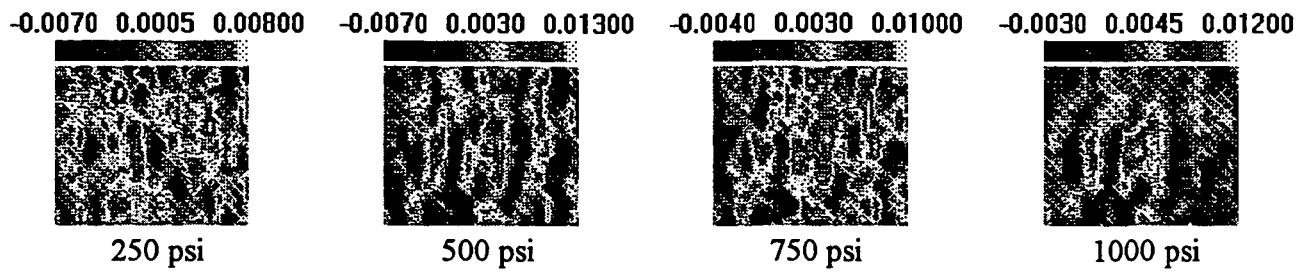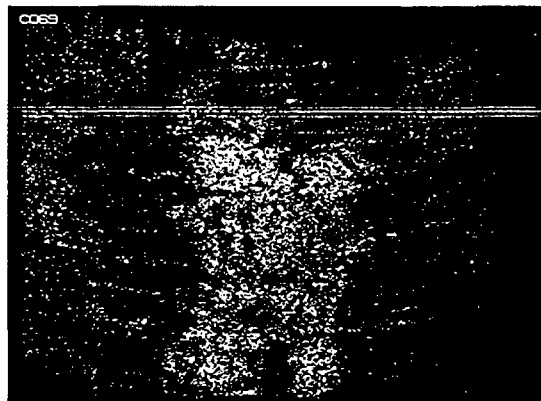(Bottle No. A003-004, Resin 3501-6 ATL)

Figure 21.b. Static Shearogram for No Impact
(Bottle No. A003-004, Resin 3501-6 ATL)

The more highly localized fiber breakage and matrix cracking caused by the sharp tipped impacts, however, did significantly concentrate the stress and strain in the damage effected zone and are readily apparent in most cases as low as 250 psig, about 6% of the expected burst pressure for the undamaged bottles. The strain fields indicate a region of intensified strain which grew larger in both size and strain magnitude with increasing pressure. In general, the ultimate failure of each FWPV was observed to have originated as the failure of hoop fiber bundles, or tows, with the same location and geometry as the hoop strain indication.

-0.0070 0.0005 0.00800   -0.0070 0.0030 0.01300   -0.0040 0.0030 0.01000   -0.0030 0.0045 0.01200

250 psi   500 psi   750 psi   1000 psi

Figure 22.a. SDVIC Hoop Strain Measurements for a Blunt Tip Low Energy Impact
(Bottle No. C069-070, Resin 3501-6 ATL)

Figure 22.b. Static Shearogram for a Blunt Tip Low Energy Impact
(Bottle No. C069-070, Resin 3501-6 ATL)

-0.00300   0.00150   0.00600   -0.00300   0.00450   0.01200   -0.00100   0.00650   0.01400   -0.00200   0.00900   0.02000

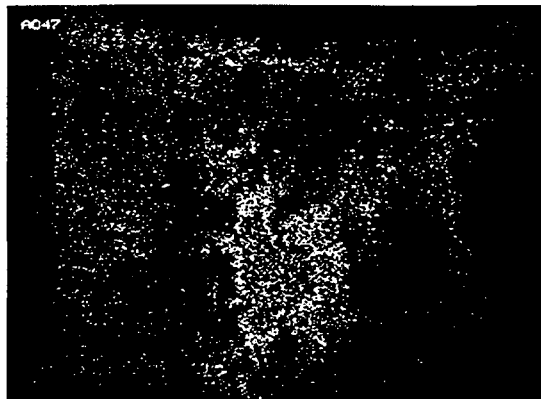250 psi   500 psi   750 psi   1000 psi
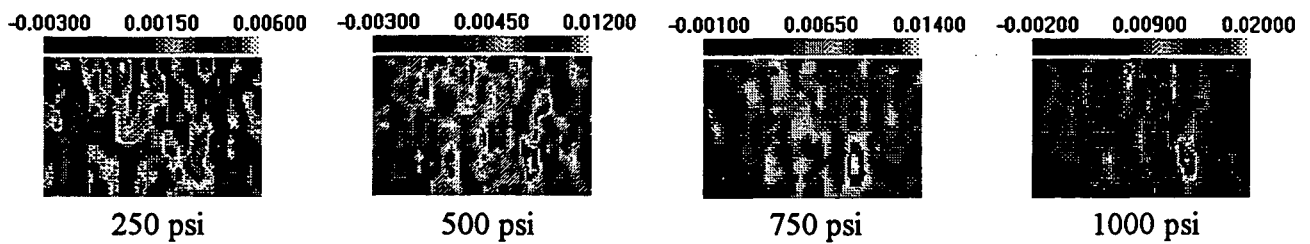
Figure 23.a. SDVIC Hoop Strain Measurements for a Blunt Tip High Energy Impact
(Bottle No. A047-048, Resin X8553-45)

Figure 23.b. Static Shearogram for a Blunt Tip High Energy Impact
(Bottle No. A047-048, Resin X8553-45)

-0.0040 0.0005 0.00500   -0.0050 0.0035 0.01200   -0.0020 0.0070 0.01600   -0.0020 0.0115 0.02500

250 psi   500 psi   750 psi   1000 psi
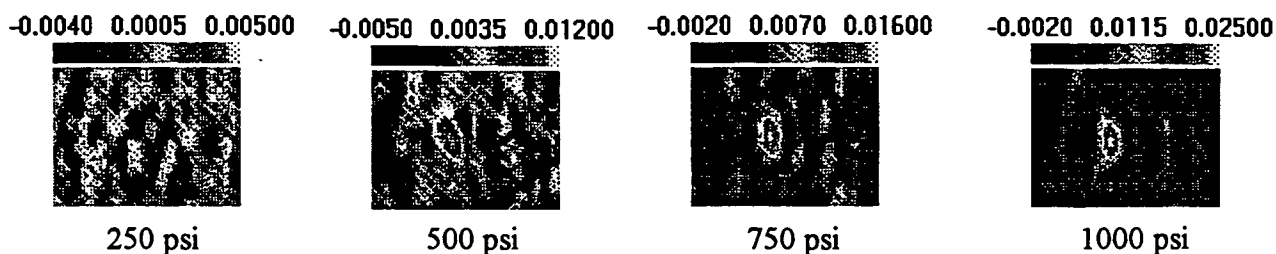
Figure 24.a. SDVIC Hoop Strain Measurements for a Sharp Tip Low Energy Impact
(Bottle No. A013-014, Resin X8553-45)

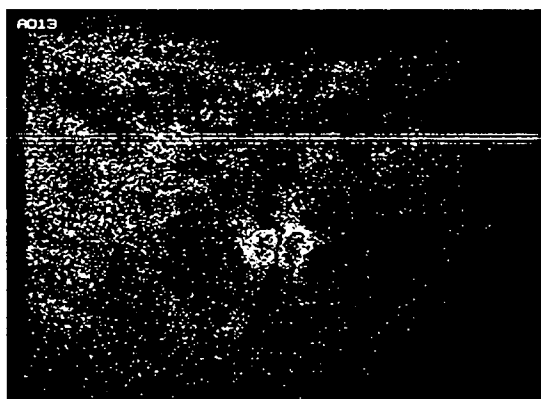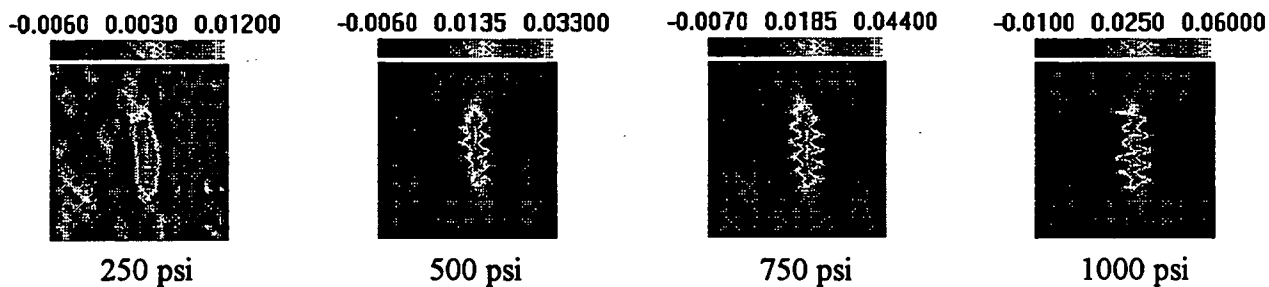**Figure 24.b.** SDVIC Hoop Strain Measurements for a Sharp Tip Low Energy Impact
(Bottle No. A013-014, Resin X8553-45)

-0.0060 0.0030 0.01200   -0.0060 0.0135 0.03300   -0.0070 0.0185 0.04400   -0.0100 0.0250 0.06000

250 psi   500 psi   750 psi   1000 psi
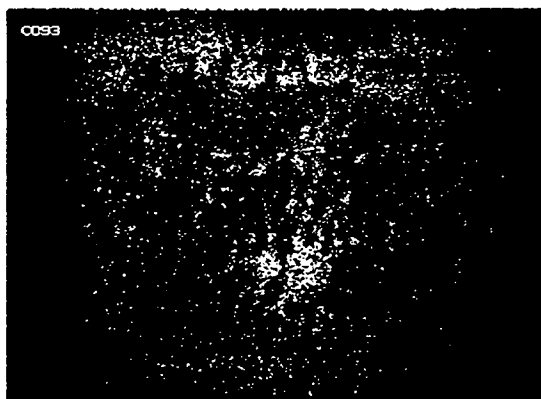
Figure 25.a. SDVIC Hoop Strain Measurements for a Sharp Tip High Energy Impact
(Bottle No. C093-094, Resin X8553-45)

Figure 25.b. SDVIC Hoop Strain Measurements for a Sharp Tip High Energy Impact
(Bottle No. C093-094, Resin X8553-45)

Among FWPV of the same resin class, the observed strain magnitude and the size of the strain concentrated region was larger at each pressure interval for the high energy sharp tip impact bottle than for the low energy sharp tip impact bottle, as illustrated in Figures 24.a. and 25.a.

In the case of the high energy impact with a sharp tip, Figure 25.a., a linear vertical strain concentrated region is clearly indicated, with much higher strains than the previous examples, up to 6%. The only visible damage at this pressure was the original indention. The first indication of eminent failure was the appearance of a visible vertical crack at elevated pressure in the final ramp to burst. The geometry of the localized region of high strain closely resembled the geometry of the first graphite tow failures. Before any damage propagation was visible to the unaided observer, SDVIC predicted the location and nature of the initial tow failures.

4.3.2. NEURAL NETWORK BURST PRESSURE PREDICTION

During burst testing of these FWPV, James Walker of the UAH Center for Automation and Robotics collected acoustic emission (AE) data for bust pressure prediction.[3,4] The AE amplitude distributions were supplied as input to a back propagation neural network (BPNN), which was trained on the data from a few FWPV and tested on the remainder. For the filled Gr-Ep FWPV, the bust pressures were estimated with an average error of 1.9%.

This success inspired development of a similar technique for use with SDVIC strain fields. However, the dissimilarities in the type of data required that some technique be found to preprocess the SDVIC data, resulting in a reduced data set of a form applicable to neural network analysis. Unfortunately, this technique was not found until most of the bottles had been burst and it required a modification in the SDVIC data acquisition.

The AE data used for BPNN analysis was in the form of a histogram, and the height of each category bar was input to a single neuron. This required as many input neurons as there were histogram categories or bars. A typical AE BPNN used 41 input neurons. In the case of SDVIC analysis, strain values are determined for a grid array of points on the bottle surface with sizes typically of 15,000 points or more. A direct input of this strain field into a BPNN would require an equal number of input neurons and would result in prohibitively time consuming analysis.

To overcome this problem, the VICNet Neural Network Interface software was developed. This program reduces the strain field data file to a histogram such as those shown in Figure 26. for two bottles with burst pressures of 2597 and 1701 psig.

In general, those FWPV with lower burst pressures tend to have a lower and wider strain distribution than those with higher burst pressures. In this form the SDVIC data may be input to a BPNN to produce a quantitative means for predicting burst pressure based upon SDVIC hoop strain measurements. Each input neuron may be assigned a strain category and assigned the number of SDVIC data points having strain values in that category. As the strain is related to FWPV failure by material properties more strongly than minor geometry differences, this technique may be capable of predicting the failure

strength of actual full scale rocket motor cases and storage vessels based upon training data obtained from smaller, less expensive specimens.
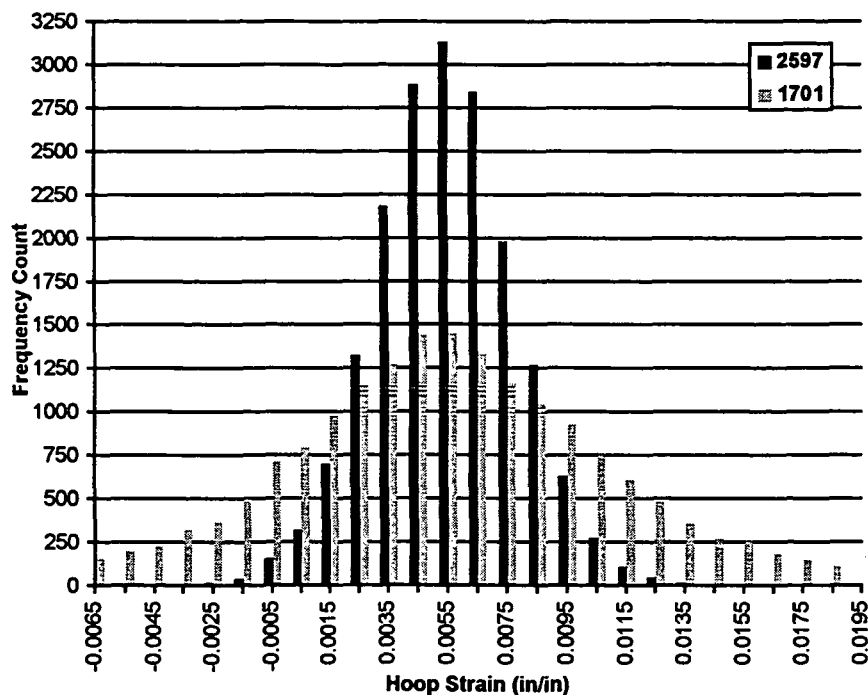

Figure 26. SDVIC Hoop Strain Histograms Generated by VICNet.

4.4. SUMMARY

Electronic Shearography inspections provided a non-contact computer vision holography method of locating and sizing internal delaminations in impact damaged filament wound pressure vessels with a single low level thermal cycle. The character of the indications suggested whether those delaminations were limited to a few plies or effected a greater thickness of the material. The shape and size of indication correlated well with the type of impact.

Sub-pixel Digital Video Image Correlation provided a non-contact computer vision method of characterizing and predicting the propagation of impact induced fiber breakage and matrix cracking in filament wound pressure vessels with internal pressurization less than 25% of the manufacturer's predicted burst pressure. Full-field measurements of displacements and strains were made by SDVIC in near-real-time and displayed in an easily interpreted graphical form. The technique allowed the visualization of deformation measurements with sub-pixel resolution.

Neural network analysis based upon SDVIC measurements is now possible and may lead to a burst pressure prediction method which may be useful in inexpensively determining the remaining life of impact damaged flight articles such as solid rocket motor cases or storage vessels.

5. SPACE SHUTTLE EXTERNAL TANK

5.1 COMPOSITE NOSE CONE

MSFC is currently developing a composite nose cone proposed for use on the Space Shuttle external fuel tank. The graphite-phenolic (Gr-Ph) design provides a considerable weight reduction compared to the current aluminum structure and elimination of spray-on thermal protection system insulation. However, since the nose cone will be exposed to supersonic airflow during flight, the design must be aerodynamically as well as structurally sound. The presence of fastener holes in the external tank composite nose cone (ET-CNC) introduces the possibility of damage caused during their machining. The use of flat headed bolts assists in the design aerodynamics but necessitates that the fastener holes take on a conical geometry, which increases the possibility for service load induced damage. Additionally, the composite design introduces the possibility for the existence of serious delaminations within the material which may not be visible to the unaided observer. The capability of the Electronic Shearography for detection of internal delaminations, for assessment of machining induced fastener hole damage, and for assessment of load induced damage to conical fastener holes in the STS ET-CNC material systems has been demonstrated.

The PW EH/SIS was used to evaluate the response of each ET-CNC material specimen to thermal excitation. The telephoto lens was focused on each region of interest individually. Static shearograms were obtained using speckle averaging and four frame averaging. No traveling fringes were displayed. A reference shearogram was obtained after the test article had been slightly heated ($\Delta T < 5°F$) with an industrial heat gun. The deformed shearogram was taken after the specimen had cooled to approximately room temperature.

5.1.1. INTERNAL DELAMINATIONS

The Nondestructive Evaluation Branch (EH13) was provided a Gr-Ph nose cone section containing three 1" square Teflon inserts. Located at increasing depths inside the nose cone wall, each insert simulates a material debond of equivalent size. The image shearing distance was set to 0.25 inches at a lens-to-object distance of 4 feet. The general vicinity but not the specific location of each insert was inspected until sufficient indication was given to locate the debonds.

Figure 27. indicates the response of an insert close to the material surface with the convex surface of the nose cone facing the shearography apparatus. The symmetric dark and light triangles in the center of the shearogram correctly indicate the size, shape, and orientation of the near-surface delamination. The boundary between the dark and light regions is approximately normal to the direction of image shear. The mottled gray region enclosing the debond indication and filling the lower left portion of the figure is the surface of the nose cone section. The lighter region above and to the right of this is the background behind the specimen. Although the debond closest to the front surface was detectable whether the concave or convex surface was facing the shearography device, inspections failed to detect the inserts at the mid-plane and near the surface away from the shearography device.
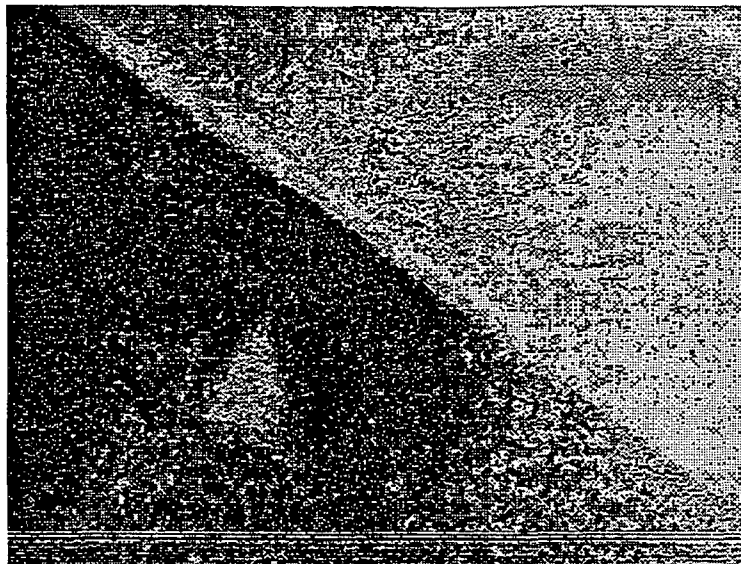
Figure 27. (N) Indication of a Simulated Delamination

5.1.2. FASTENER HOLES

The use of metallic bolts to fasten the ET-CNC to the internal structure requires characterization of machining and load induced damage around fastener holes of various proposed geometries. The capability of electronic shearography to detect such damage has been demonstrated.

5.1.2.1. MACHINING DAMAGE TO CYLINDRICAL HOLES

The MSFC NDE Branch was provided a Gr-Ph coupon containing four drilled holes. The geometry of this specimen is shown in Figure 28. The specimen is 6" × 6" × 1/4" thick and curved to the same radius as the ET-CNC. A 1/4" hole has been drilled in each corner. The image shearing distance was set to 0.3" at a lens-to-object distance of 4.5'. The telephoto lens was focused on each hole individually at maximum zoom.

For this experiment, the sensitivity has been adjusted such that the small motion of the undamaged part produces a dark zero-order fringe, while the greater motion of the damaged regions produces bright one-half-order and greater fringes. Electronic shearograms of two machined holes appear in
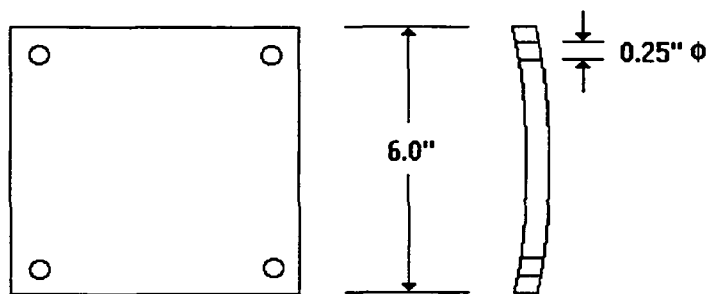

Figure 28. Gr-Ph ET-CNC Coupon with Machined Holes

Figures 28. and 30. Each image contains the appearance of each hole twice due to an image shearing distance 0.05 inches greater than the diameter of the holes.

Figure 29. is a shearogram of a hole with no damage visible to the unaided observer. However, the shearogram indicates a damaged region with a diameter of 0.290 inches. That is, the damage extends radially 0.02 inches beyond the drilled hole.

Figure 30. is a shearogram of a hole with visible machining damage in the form of frayed material inside the hole at the surface. The shearogram also indicates a damaged region with a diameter of 0.485 inches. That is, the damage extends radially 0.118 inches beyond the drilled hole. The latter damage is not visible to the unaided observer, but extends to almost twice the diameter of the intended hole.
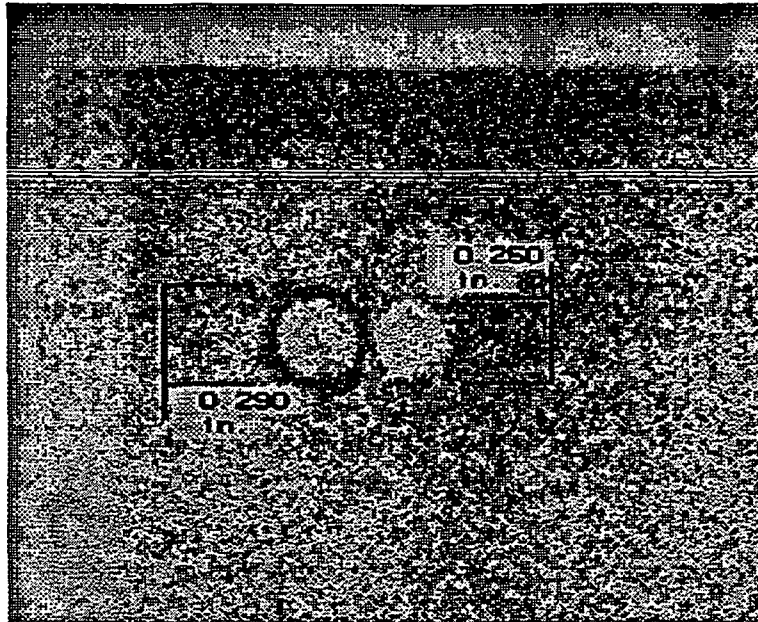

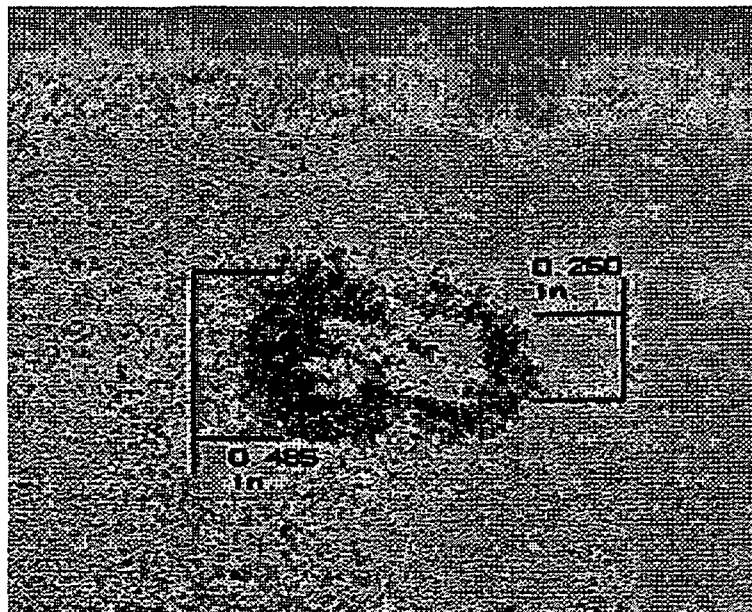**Figure 29.** (N) Electronic Shearogram of Machined Hole with No Visible Damage

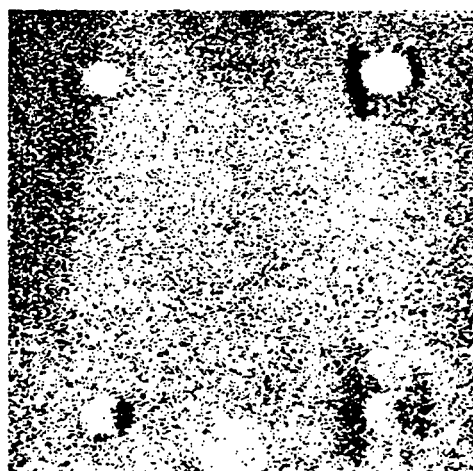**Figure 30.** (N) Electronic Shearogram of Machined Hole with Visible Damage

5.1.2.2.   MACHINING DAMAGE TO CONICAL HOLES

The MSFC NDE Branch was provided a Gr-Ph coupon containing four drilled holes tapered to accommodate flat-headed fasteners. The geometry of this specimen is shown in Figure 31. The specimen is 6" × 6" × 1/4" thick and curved to the same radius as the ET-CNC. A 0.25 in. ID conical hole has been drilled in each corner. The image shearing distance was set to 0.063 inches at a lens-to-object distance of 4.5 feet.
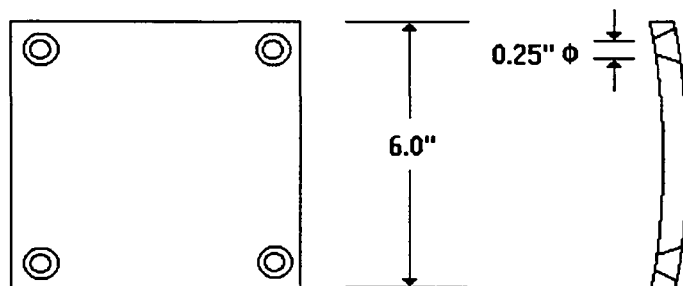
Figure 31. Gr-Ph ET-CNC Coupon with Conical Holes

For this experiment, the sensitivity has been adjusted such that the small motion of the undamaged part produces a dark zero-order fringe, while the greater motion of the damaged regions produces bright one-half-order and greater fringes. An electronic shearogram of these machined holes appears in Figure 32.

Figure 32. (N) Machining damage in conical fastener holes.

5.1.2.3.   LOAD INDUCED DAMAGE TO CONICAL HOLES

The MSFC NDE Branch was provided a Gr-Ph coupon containing three conical holes. The geometry of this specimen is shown in Figure 33. A bolt in each hole was used to apply load, as illustrated in Figure 34. Tension was applied such that the coupon and the bolts were pulled in opposite directions. The direct bearing load between the metal

fastener and the Gr-Ph coupon caused visible damage inside the conical shaped holes. The image shearing distance was set to 0.13 inches at a lens-to-object distance of 4 feet. The telephoto lens was focused on each hole individually.

For this experiment, like the previous one, the sensitivity has been adjusted such that the small motion of the undamaged part produces a dark zero-order fringe, while the greater motion of the damaged regions produces bright one-half-order and greater fringes. Electronic shearograms of the three machined holes appear in Figures 35., 36., and 37. The appearance of each hole is elongated somewhat horizontally due to image shearing in that direction. However, the material was loaded in the vertical direction and, as there is no vertical shear, measurements of the extent of the damage may be made in this direction.

The shearograms of all three holes feature bright crescent shaped indications above the holes. This is the side against which the bearing load was applied by the bolts and upon which damage was observed visually.
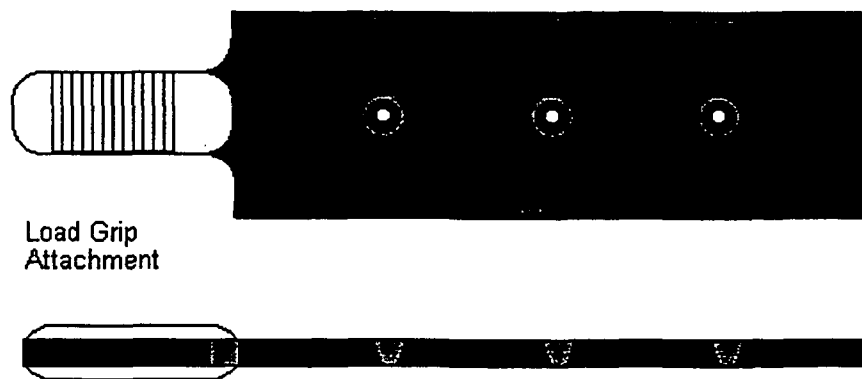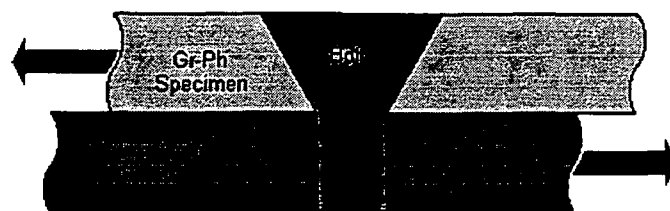

Load Grip
Attachment

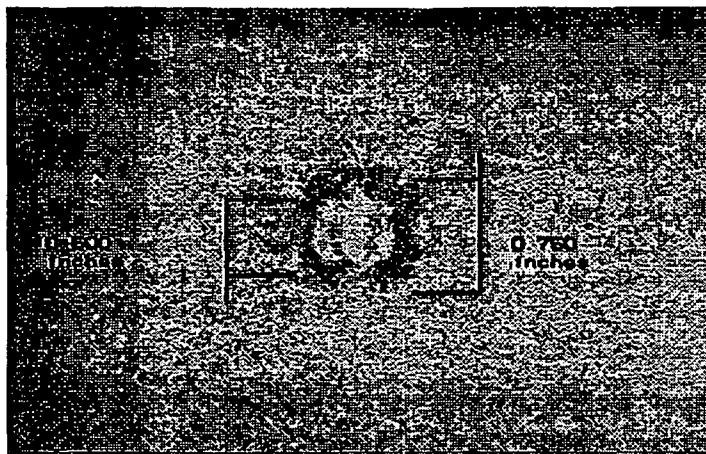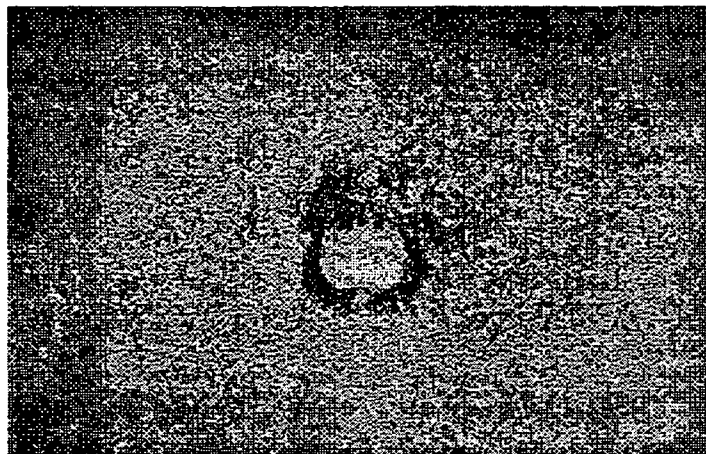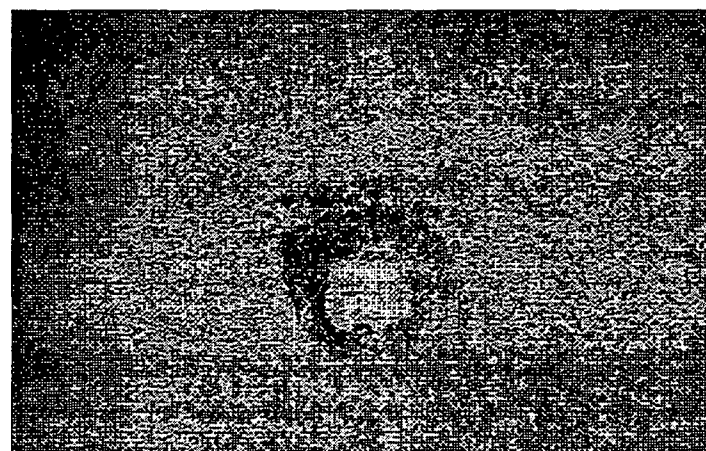**Figure 33.** Specimen Geometry

Figure 34. Bolt Loading Arrangement

Figure 35. (N) Electronic Shearogram of Conical Hole Nearest to Load Grip.

Figure 36. (N) Electronic Shearogram of Middle Conical Hole.

Figure 37. (N) Electronic Shearogram of Conical Hole Farthest from Load Grip.

5.1.2.4. SUMMARY

It has been demonstrated that electronic shearography is capable of detecting near-surface delaminations in Gr-Ph composite materials. Inspections may be performed for both the concave and convex surfaces of the nose cone. However, debonds near the mid-plane of the nose cone wall may not be detected.

It has been demonstrated that electronic shearography is capable of assessing the extent of damage induced during the machining of Gr-Ph composite materials. While most machining operations introduce some localized damage, determination of the degree to which this has occurred may be made quickly and easily based upon the indication size

It has been demonstrated that electronic shearography is capable of assessing the extent of damage induced during the loading of conical fastener holes in Gr-Ph composite materials. The indicated damage lies outside the conic section of the holes. Electronic shearography thus provides a non-contact technique for nondestructively evaluating load induced damage around these holes without removing the fastener.

5.2. LIQUID OXYGEN FEED LINE FAIRING

This fairing covers the junction between the space shuttle external tank and the liquid oxygen feed line which supplies the space shuttle main engines (SSME). It is constructed as a graphite-polyimide (Gr-Pim)composite. The possibility exists that delaminations could form as a result of exposure to the heat and stress created during atmospheric flight. To simulate this, a hot gas stream was blown across a curved Gr-Pim coupon. Two delaminations were subsequently visible along the same edge of the specimen at different depths; one close to the outer surface and one closer to the mid plane than the inner surface. Ultrasonic testing (UT) conducted by Mike Suits and Jeff Leak of the NDE branch resulted in a large indication along that edge and extending into the heart of the acreage of the coupon. This UT indication was the cumulative effect of all delaminations, and it was indeterminate how much of the indication was produced by each of the delaminations visible on edge. It was also unknown whether the indications were influenced by internal flaws which were not visible on edge.

An ES inspection was conducted for this specimen with radiant thermal excitation. Two 500 Watt Halogen bulbs were directed toward the specimen surface for five minutes. Static shearograms were recorded as the specimen cooled and the excited delaminations relaxed. As shown in Figures 38. and 39., a large circular delamination extending to the edge was detected near the outer surface of the specimen and no delaminations were detected near the outer surface. Based upon these inspections, it is concluded that the portion of the UT indication along the specimen edge corresponds to the visible delamination near the mid plane which was not detected with ES. The portion of the UT indication which extends into the acreage of the coupon corresponds to the circular ES indication and the visible delamination near the outer surface of the material. There is nothing to suggest that any other delaminations of the same magnitude are present in the coupon.
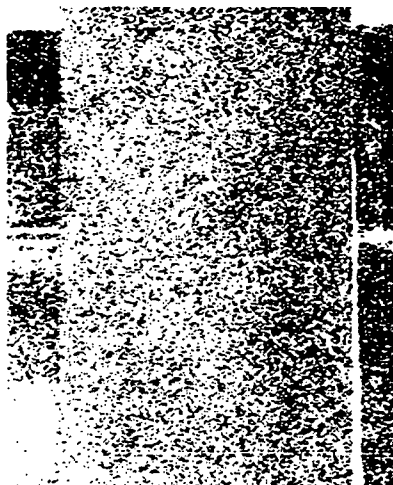
Figure 38. (N) No delaminations detected from inner surface.

Figure 39. (N) Large delamination detected from outer surface.

6. PEGASUS FAIRING THERMAL PROTECTION SYSTEM

The Pegasus launch vehicle is a multiple stage rocket manufactured by Orbital Science Corporation (OSC). Originally, the Pegasus and its payload of up to five satellites were carried to an initial altitude and then launched from beneath the wing of an Air Force B-52. OSC subsequently purchased a Lockheed L-1011 and outfitted it such that Pegasus rockets could be carried to altitude and launched from beneath the belly of the aircraft. Such a launch attempt in March of 1995 was aborted prior to release of the Pegasus when the Thermolag T230 thermal protection system (TPS) peeled off of the rocket's nose cone. The TPS is a thin layer of material designed to insulate the satellites inside the nose cone from the frictional heating on the outer surface of the rocket while it is accelerating through the atmosphere. The fairing shell, composed of graphite epoxy composite skins over an aluminum honeycomb core, may also be subject to thermal damage without the presence of the TPS. The L-1011 landed with the Pegasus still attached. Two of the satellites aboard the aborted launch vehicle were the NASA Orbital Transient Detector, an atmospheric lightening tracking device with development and operation managed by MSFC, and the ORBCOMM communications satellite, for which the vehicle was named.

Three engineers from MSFC, Sam Russell (Non-Destructive Evaluation Branch), Mike Prince (Polymers and Composites Branch), and Floyd Roberts (Ceramics and Coatings Branch), traveled to OSC's Pegasus assembly facility in Phoenix, Arizona to assist in the evaluation of the TPS problems. The NDE Branch shipped to OSC their Laser Technology, Inc. (LTI) electronic shearography device by next day air freight for evaluation of the TPS bond line integrity before and after repair attempts. The NASA engineers were accompanied by a UAH Research Associate to study the application of electronic shearography in an actual service environment, as well as to assist in the development of techniques for inspection of the Pegasus TPS and training of OSC personnel in the operation of the shearography apparatus.

After the remaining TPS was stripped from the nose cone, it was replaced with an inner layer of cork and an outer layer of RTV. Other areas were repaired by injecting adhesive beneath the unbonded Thermolag. ES inspections were conducted over the

majority of the surface of each fairing before and after these repairs. The repaired ORBCOMM Pegasus was launched successfully on 3 April 1995.

6.1. PROCEDURE

The Pegasus fairing consists of a right and left half with the nose cone attached to the left side. The nose cone is quasi-hemispherical and attached to the cylindrical section by a short frustum as shown in Figure 40. During inspection the fairings were supported from the inside on a wheeled cart. In this position, the actual side of the fairing appears to be the top. The two halves of the fairing are bound with steel bands during launch and there are two black rings around the fairing which are bare of TPS to accommodate these straps. The optical head, containing the laser illumination source and the optics and CCD camera for image acquisition, was positioned on its tripod approximately 3 to 6 feet from the fairing. The apparatus is visible in the left portion of Figure 40., and the laser illumination is apparent as a bright circle on the side of the fairing at the aft retaining band ring. ES inspections were not possible for a region approximately two feet wide and extending from approximately two feet behind the nose cone to approximately two feet ahead of the aft edge because the tripod did not provide sufficient elevation.

Figure 40. Electronic Shearography inspection of ORBCOMM Pegasus fairing at OSC manufacturing facility in Phoenix, Arizona.

Inspections were conducted with convective thermal excitation provided by an industrial heat gun. The heated delaminations expanded in a curved fashion away from the surrounding bonded regions due to the constraint provided there. Reference images were acquired while the region was still warm and these were processed with subsequent images after the region had cooled. The cooled delaminations had relaxed back toward their original shape, and the change in surface contour during this relaxation appears in the shearograms as bright fringes.

6.2. ORBCOMM

The location of each unbond detected on the ORBCOMM fairing is indicated in Figures 41. through 43. Each indication is shown and discussed individually in Figures 44. through 53.

Figure 41. Left Fairing/Top Side

Figure 42. Left Fairing/Bottom Side

Figure 43. Right Fairing/Top Side

Figure 44. Glued joint filler indications in cork nose cone repair.
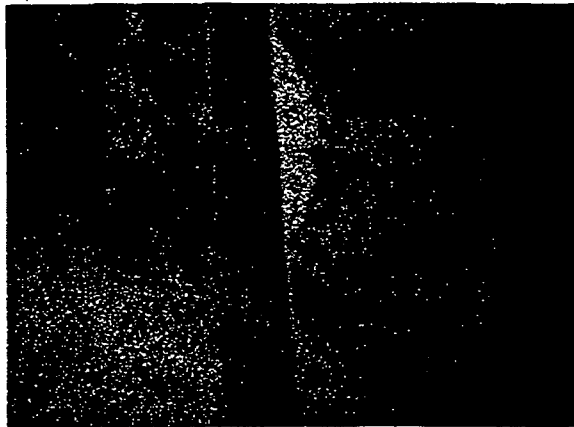
Figure 45. Indication C1.
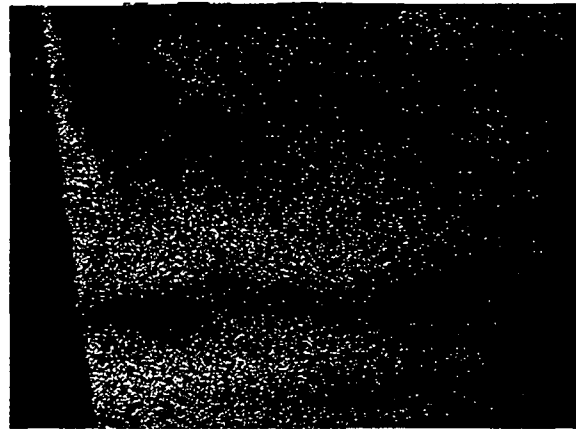
Figure 46. Indication C2.
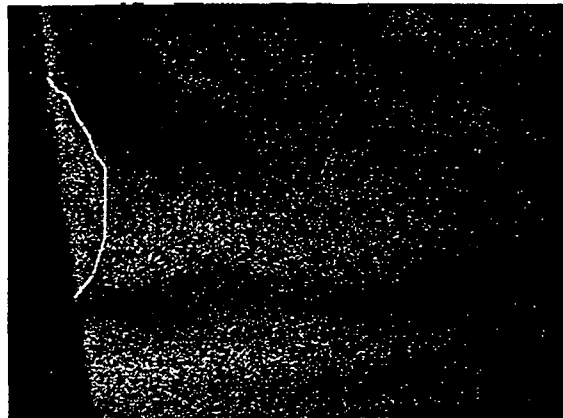
Figure 47. Indication C2 outlined for clarity.
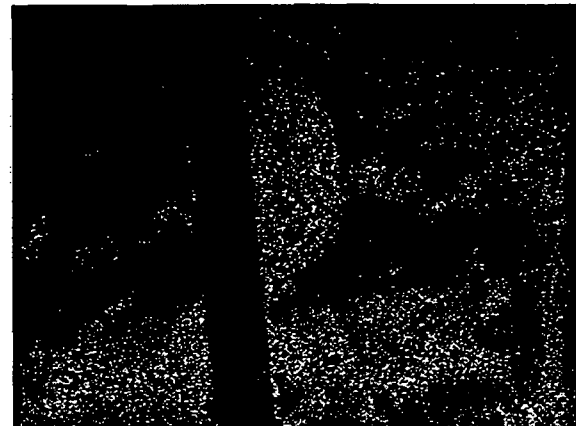
Figure 49. Indications C3 and C4.
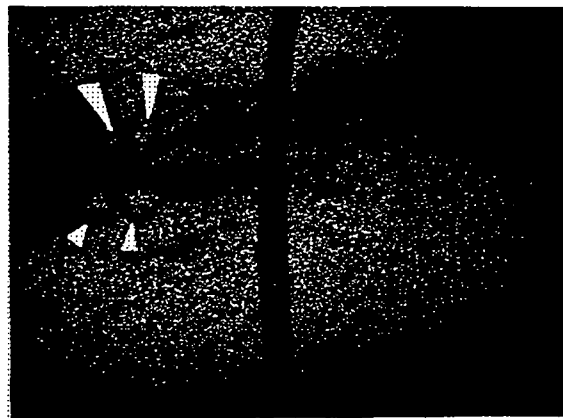
Figure 50. Indication C5, four circular test plugs through the composite beneath TPS.

Figure 51. Indication C6.
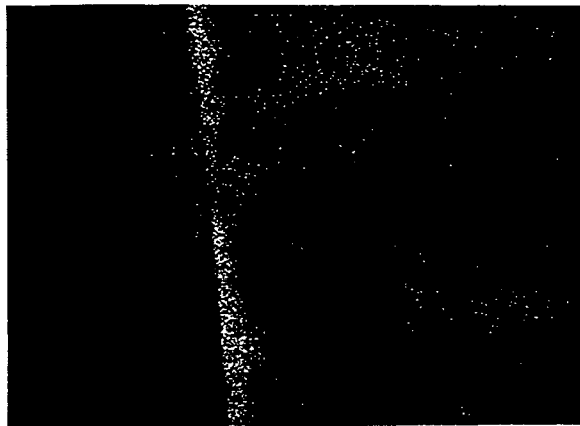
Figure 52. Indications C7 and C8, prior to repair.

Figure 53. Indications C7 and C8, following repair.

6.3. SEASTAR

At the same time that the ORBCOMM Pegasus fairing was being repaired, another fairing was being manufactured for use in the upcoming SEASTAR launch. This second fairing was also inspected, and numerous unbonds were detected. The location of each unbond detected on the SEASTAR fairing is indicated in Figures 54. through 57. Each indication is shown and discussed individually in Figures 58. through 71.
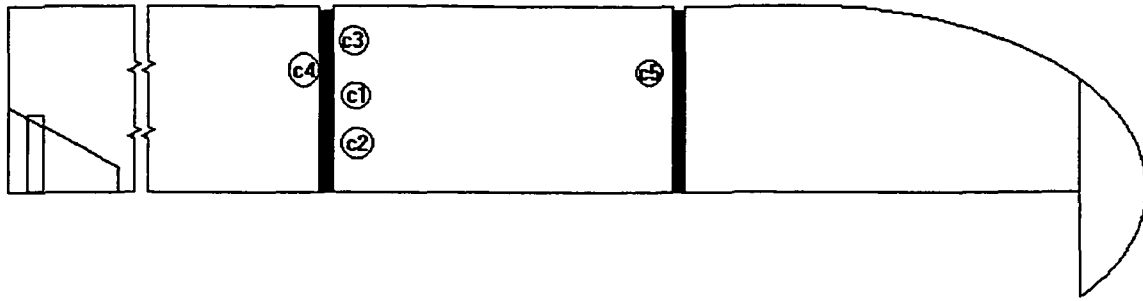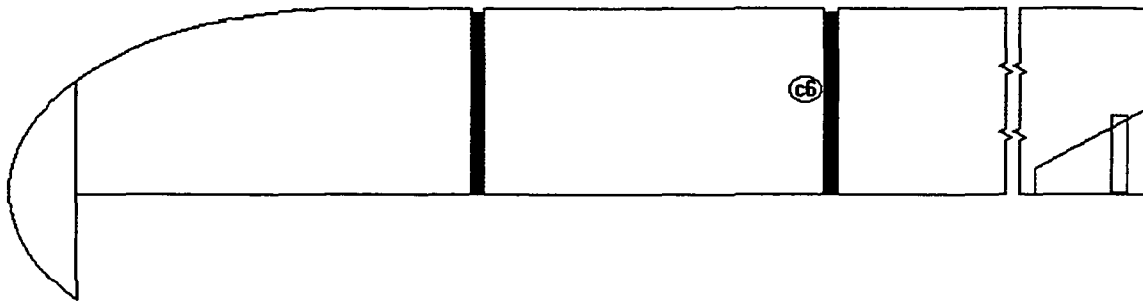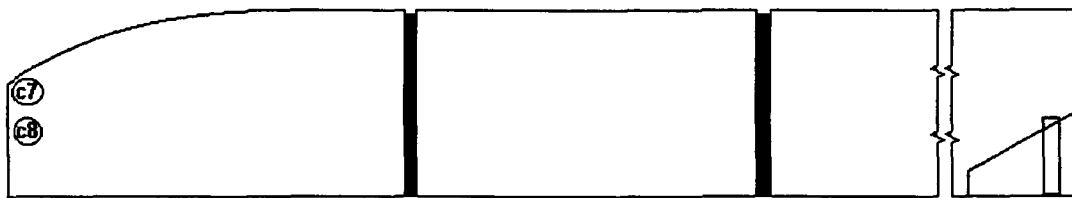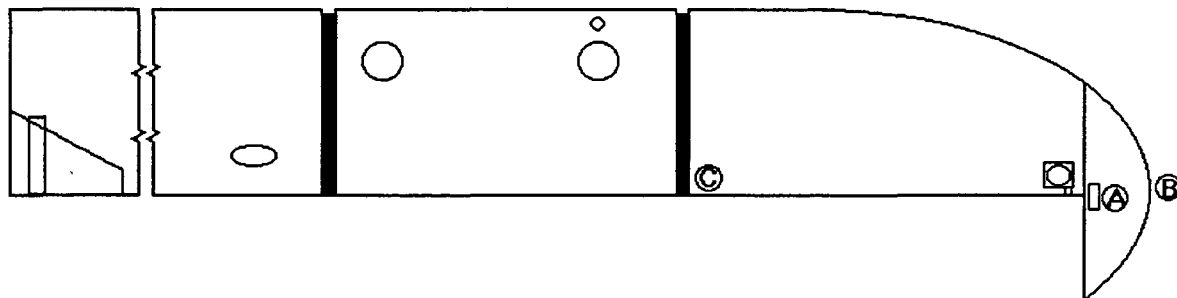

Figure 54. Left Fairing/Top Side
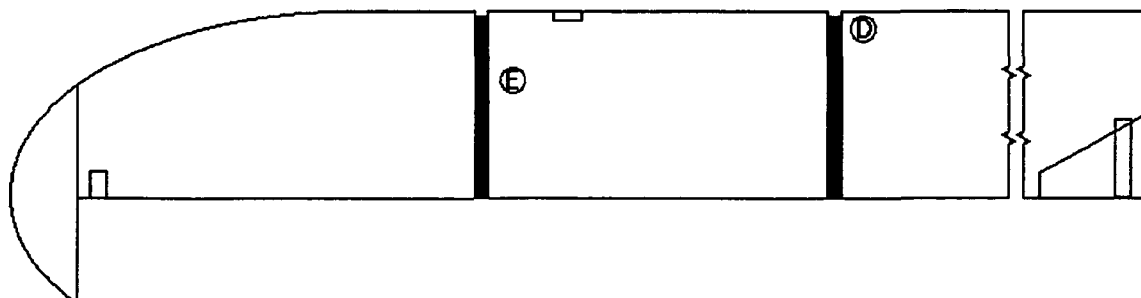

Figure 55. Left Fairing/Bottom Side
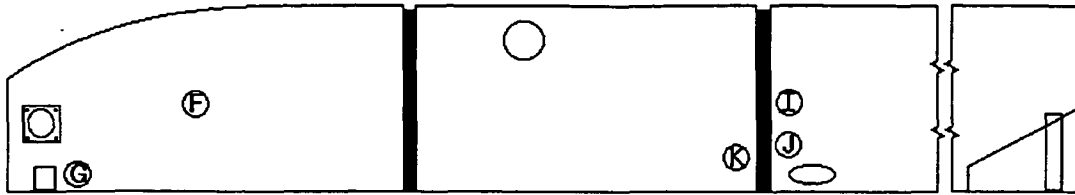
Figure 56. Right Fairing/Top Side
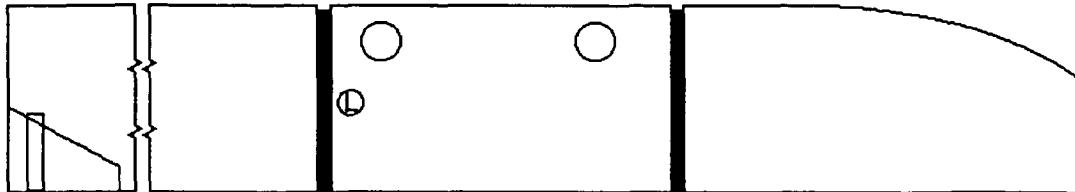
Figure 57. Right Fairing/Bottom Side
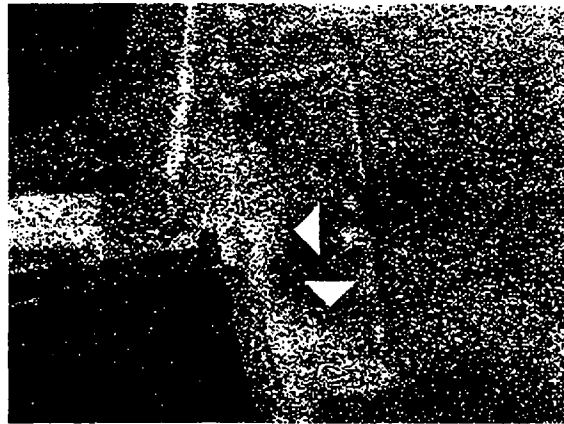
Figure 58. Indication A, unbonds along the edge of a rectangular cork insert adjacent to a square and a circular cutout.
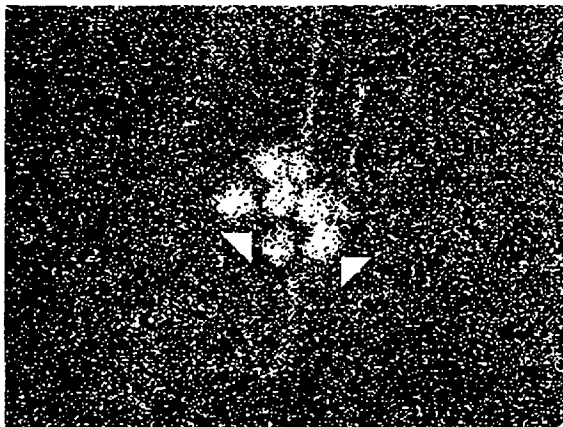
Figure 59. Indication B, diagonally sheared.
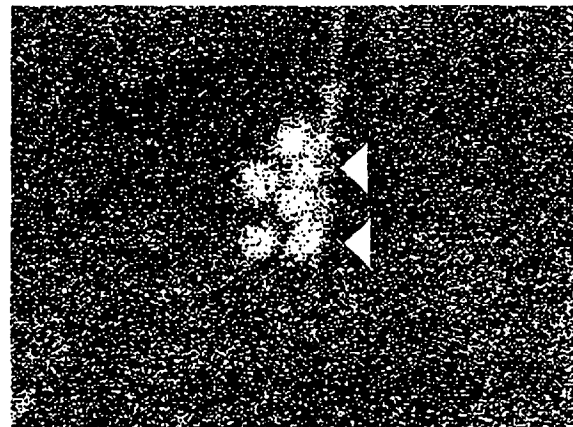
Figure 60. Indication B, vertically sheared.

This indication is that of three separate anomalies, each of which appears twice due to image shearing. In each of these two figures, the two spots with pointers are dual images of the same anomaly. This was later learned to be a glob of RTV used to position a thermocouple during curing. The other four indications in each figure are the dual images of two anomalies, holes drilled through the composite beneath the cork TPS.
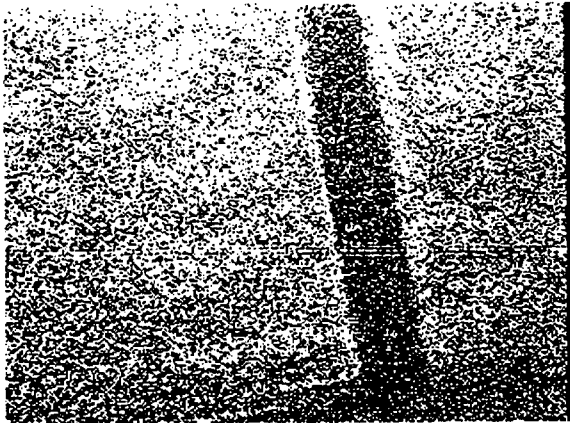
Figure 61. Indication C.
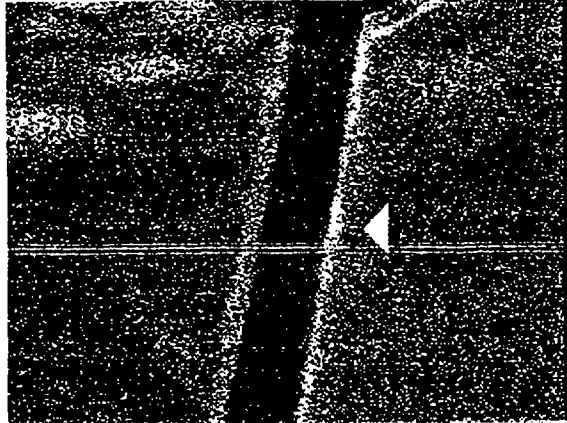
Figure 62. Indication D.
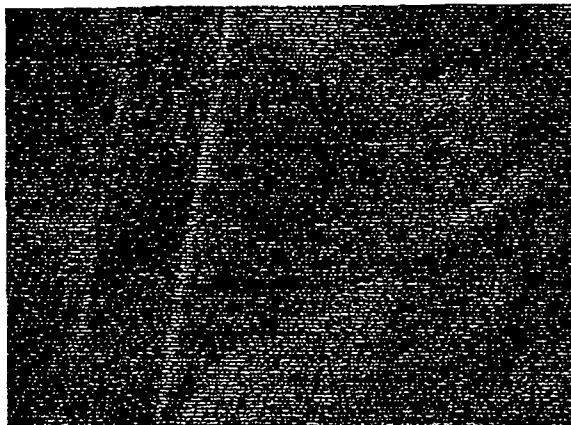
Figure 63. Indication E.
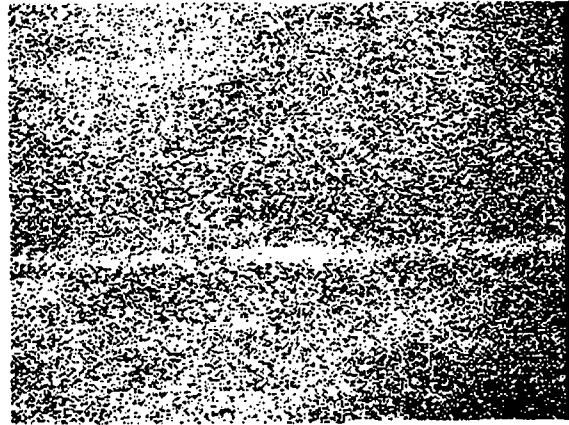
Figure 64. Indication F.
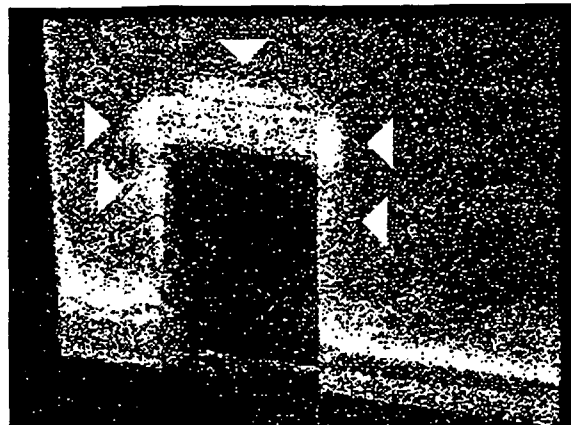
Figure 65. Indication G, vertical shear.
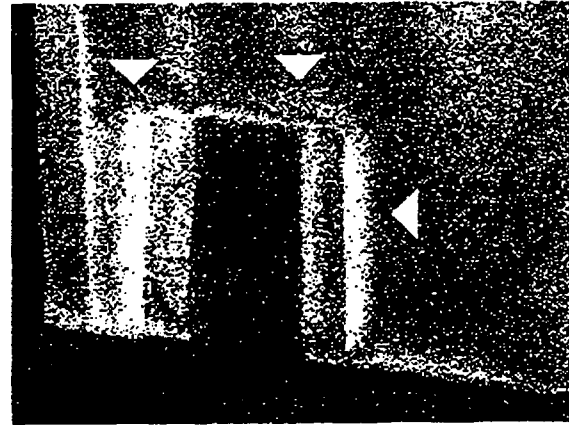
Figure 66. Indication G, horizontal shear.

Delaminations were indicated along all three edges of this cutout, as indicated by the pointers in the figures. Shearograms were recorded with both horizontal and vertical shearing vectors to separate the delamination indications from edge effects.

Figure 67. Indication H, low heat.
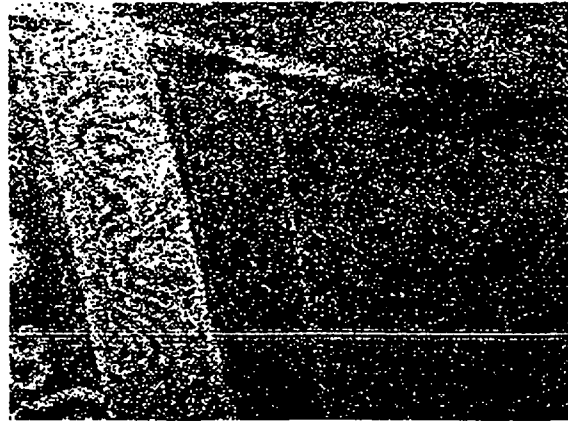
Figure 68. Indication H, high heat.

These indications were obtained from a section of cork which had been positioned with tape but not yet bonded. This simulated delamination was used to develop inspection procedures for other regions. Heating the region longer with the heat gun produced more fringes, but reflected the same modal distortion as evidenced by the similar fringe pattern in both figures.
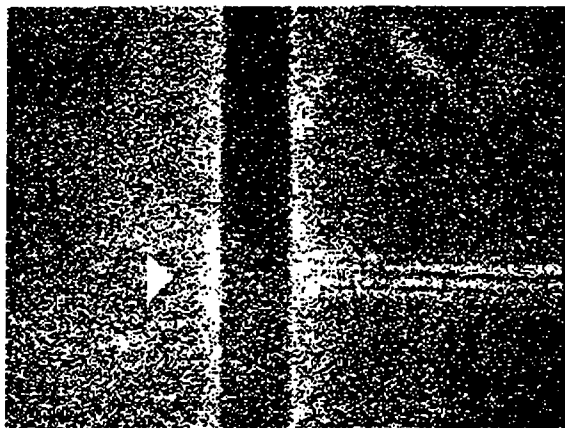
Figure 69. Indication I.
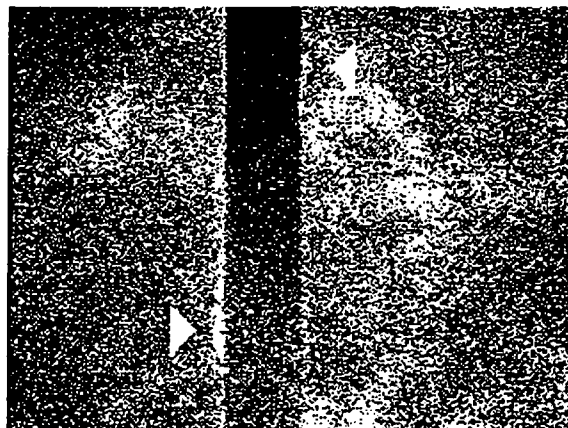
Figure 70. Indications J and K.
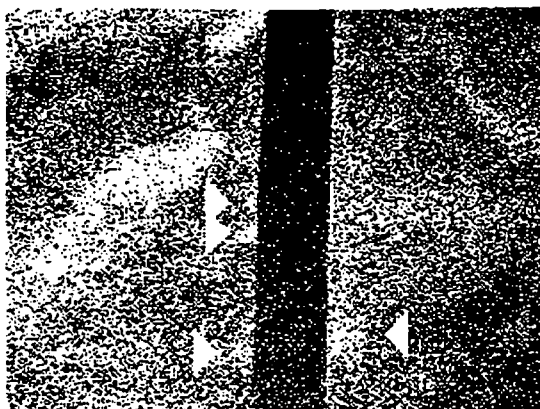
Figure 71. Indication L.

7. SOLAR X-RAY IMAGER TELESCOPE TUBE

The Solar X-ray Imager (SXI) telescope, to be incorporated into a Geostationary Operational Environment Satellite (GOES), utilizes a graphite-cyanate ester tube body. A cursory inspection was made of the ends of the tube to check for machining damage incurred during trimming of the cured lay-up. Inspections were performed with thermal excitation. The image shearing distance was adjusted to 1 inch with a field of view of 6 inches at an object distance of 5 feet. Figure 72. is typical of these inspection results, which indicated no significant flaws. Although a removable flat white coating is typically used for ES inspection of such dark

Figure 72. No significant flaws detected.

and shiny surfaces as that of this tube, none was used in this instance due to the optical application of this flight article. Inspection reliability may have been compromised by glare and optical absorption, as well as the lack of procedural development.

8. CRACK TIP STRESS INTENSITY FACTOR MEASUREMENT

8.1. CRACK TIP PLASTIC ZONE

The elevated stress state at the tip of a crack may cause the material in that region to yield although the material away from the crack tip remains elastic. The boundary between the plastic near field and elastic far field provides a boundary condition or constraint which may force the material in the near field to "dimple", or deform more in the thickness direction than the surrounding material. The degree to which the near field stress is elevated is often characterized in terms of a fracture mechanics parameter referred to as the stress intensity factor (K). Several analytical forms have been found for the size and shape of this 3-D plastic zone, which compare with varying favor to experimental attempts at empirical measurement[13, p111-112; 18, p106-107]. Many of these experimental methods, such as replication, require data to be collected after the load has been removed from the specimen. In this case, the removal of the far field load induces compressive

residual forces which reduce the apparent size of the 3-D zone. Other techniques, such as moiré interferometry, are overly sensitive to environmental conditions, such as load frame motor vibration, and require extensive isolation.

A short feasibility study was conducted to determine the potential for measurement of K with shearography. A single edge notch (SEN) specimen was constructed as shown in Figure 73. from polycarbonate for Mode I, or opening mode, loading. The specimen was loaded at a displacement controlled rate of 0.005 inch per minute. The image shearing distance was adjusted to approximately 0.004 inch at an object distance of 3.5 feet.
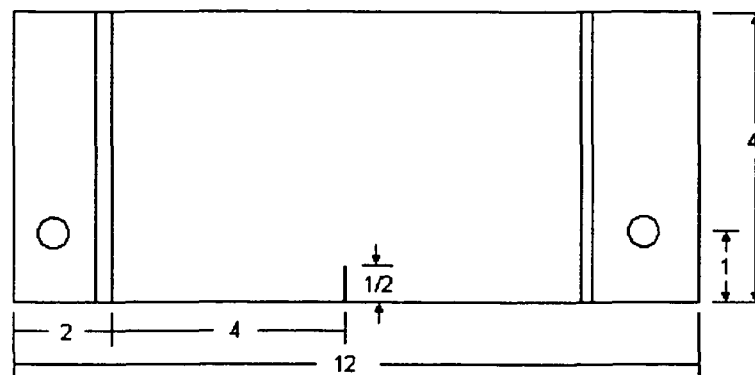
Figure 73. SEN specimen geometry, all dimensions in inches.

After an extension of 0.005 to 0.010 inches, the crosshead motion was stopped while static shearograms were acquired. The background vibration of the part and load relaxation due to creep during each hold, rather than interfering with shearography measurements, served as a source of motion for shearography measurements. That is, the vibration and relaxation caused the plastic zone to change shape between reference and subsequent images, thus indicating the reference size and shape of the 3-D zone. The 3-D zone was observed to increase in size as far field extension was increased and displayed an expected cardioid shape, as shown in Figures 74. through 79.

Image processing may be used to enhance the shearograms for determination of a closed form description of the plastic zone size and shape. An portion of an original shearogram is shown in Figure 80. Figure 81. contains the same shearogram after having been smoothed by the Blur utility from Adobe PhotoShop 4.0. Smoothing is necessitated by the speckle pattern superimposed upon the image by the nature of electronic shearography. By applying a threshold, or contrast enhancement, to the smoothed image, an outline of the detected 3-D zone may be obtained, as shown in Figure 82. A least squares regression may be utilized to fit a cardioid, as given by EQ.1., to the indicated boundary, and the solution used to predict K_I.

$$r = a(1-cos\theta) \qquad\qquad \lessdot EQ.1. \gtrdot$$
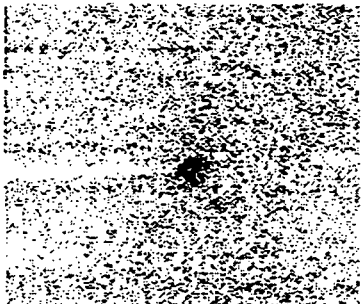
Figure 74. (N) 0.180 in. end displacement.
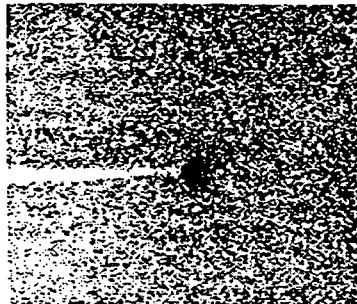
Figure 75. (N) 0.190 in. end displacement.
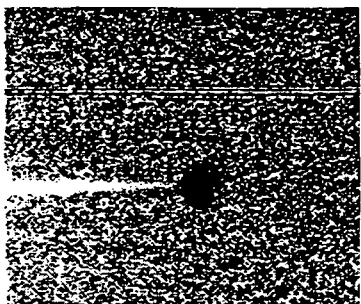
Figure 76. (N) 0.195 in. end displacement.
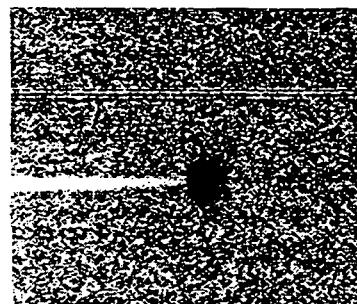
Figure 77. (N) 0.200 in. end displacement.
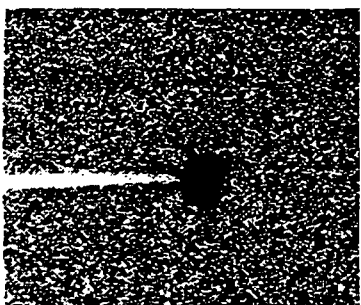
Figure 78. (N) 0.205 in. end displacement.
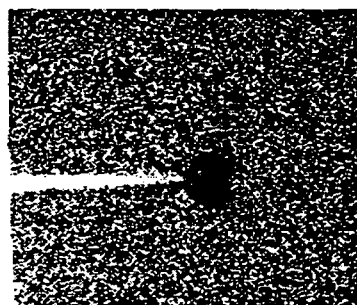
Figure 79. (N) 0.210 in. end displacement.
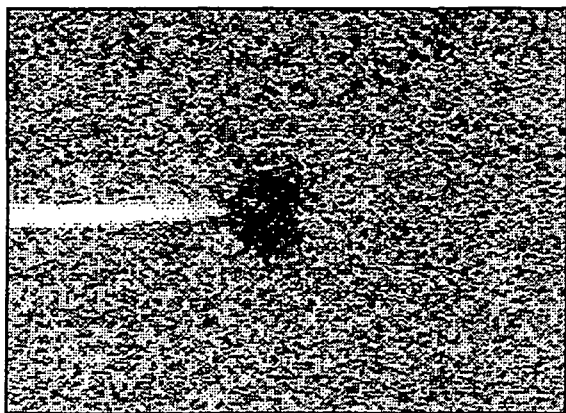
Figure 80. (N) Original Shearogram.
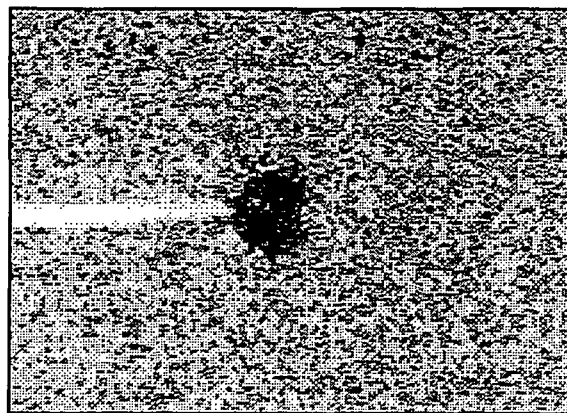
Figure 81. (N) Smoothed Shearogram.
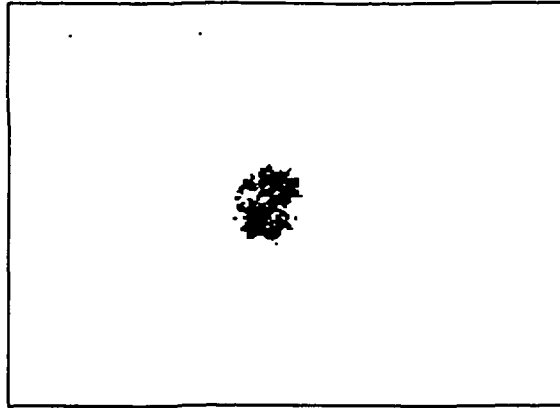
Figure 82. (N) Contrast Enhanced and Smoothed Shearogram.

8.2. ELASTIC DEFORMATION FIELD

The presence of a plastic zone at the tip of a crack effectively reduces K_I, as the crack influences the far field as though it were more blunt than it actually is. More accurate measurements of K_I may be made with less theoretical difficulty and more experimental effort from the far field deformation around a crack tip with little plasticity.

The elastic change in thickness of a specimen due to an applied load may be expressed as[13, p377]:

$$\Delta t = -\frac{t\upsilon}{E}\left(\sigma_{xx} + \sigma_{yy}\right) \qquad \text{◀ EQ.2. ▶}$$

Assuming symmetrical deformation, the out-of-plane displacements on each surface are one-half of the change in thickness.

$$w = \frac{\Delta t}{2} = -\frac{t\upsilon}{2E}\left(\sigma_{xx} + \sigma_{yy}\right) \qquad \text{◀ EQ.3. ▶}$$

$$\therefore \quad \frac{\partial w}{\partial x} = -\frac{t\upsilon}{E}\frac{\partial}{\partial x}\left[\frac{1}{2}\left(\sigma_{xx} + \sigma_{yy}\right)\right] \qquad \text{◀ EQ.4. ▶}$$

Following the elasticity theory used in similar isopachic photoelastic fringe analysis[13, p517], directly ahead of the crack tip ($\theta = 0$, $r = x$),

$$\frac{1}{2}\left(\sigma_{xx} + \sigma_{yy}\right) = \frac{K_I}{\sqrt{2\pi x}} + B_0 + A_1\sqrt{x} + B_1 x + A_2\sqrt{x^3} + B_2 x^2 \qquad \text{◀ EQ.5. ▶}$$

$$\therefore \quad \frac{\partial}{\partial x}\left[\frac{1}{2}\left(\sigma_{xx} + \sigma_{yy}\right)\right] = \frac{-K_I}{2\sqrt{2\pi x^3}} + \frac{A_1}{2\sqrt{x}} + B_1 + \frac{3}{2}A_2\sqrt{x} + 2B_2 x \qquad \text{◀ EQ.6. ▶}$$

Substitution of EQ.6. into EQ.4. gives:

$$\frac{\partial w}{\partial x} = \frac{t\upsilon}{E}\left[\frac{K_I}{2\sqrt{2\pi x^3}} - \frac{A_1}{2\sqrt{x}} - B_1 - \frac{3}{2}A_2\sqrt{x} - 2B_2 x\right] \qquad \lessdot \text{EQ.7.} \gtrdot$$

Optical consideration of the ES apparatus indicates that, with proper apparatus setup[6],

$$\frac{\partial w}{\partial x} = \frac{n\lambda}{2s} \qquad \lessdot \text{EQ.8.} \gtrdot$$

where $\partial w/\partial x$ is the change in surface slope, n is the fringe count, λ is the illumination wavelength, and s is the image shearing distance.

$$\therefore \qquad n = \frac{st\upsilon}{\lambda E}\left[\frac{K_I}{\sqrt{2\pi x^3}} - \frac{A_1}{\sqrt{x}} - 2B_1 - 3A_2\sqrt{x} - 4B_2 x\right] \qquad \lessdot \text{EQ.9.} \gtrdot$$

An experiment similar to the feasibility study discussed above, with a sharp crack instead of a notch and greater vibration isolation, could be used to estimate K_I using EQ.9. Plasticity at the crack tip should be minimized, and shearograms should be obtained with a reference at no load processed with images at load. The appearance of five fringe orders, and the measurement of their position straight ahead of the crack tip, are necessary for substitution into EQ.9. This gives five equations and five unknowns, from which values may be obtained for K_I, A_1, B_1, A_2, and B_2.

This experimental measurement may be compared with theoretical values. For a Mode I single edge crack (SEC) specimen[19, p85]:

$$K_I = Y\sigma\sqrt{a} \qquad \lessdot \text{EQ.9.} \gtrdot$$

$$\text{where} \quad Y = 1.99 - 0.41\left(\frac{a}{W}\right) + 18.7\left(\frac{a}{W}\right)^2 - 38.48\left(\frac{a}{W}\right)^3 + 53.85\left(\frac{a}{W}\right)^4$$

For the specimen to be tested in this study, $a/W = 0.125$, $t = 0.093$ in., with E = 360 ksi. and $\upsilon = 0.38$[13, p478], EQ.9. results in $Y = 2.17$ and $K_I = 1.53\ \sigma\ \text{in}^{1/2}$.

9.   CONTROL SETTINGS INFLUENCE PROBABILITY OF DETECTION

Under ideal circumstances, the change in surface slope indicated by electronic shearography may be related to the fringe count by EQ.8.

$$\frac{\partial w}{\partial x} = \frac{n\lambda}{2s} \qquad \lessdot \text{EQ.8.} \gtrdot$$

This expression indicates that for a given amount of motion, the number of fringes indicated is directly proportional to the image shearing distance. Similarly, a smaller amount of motion may be detected as a single fringe if s is increased. Since the amount of motion produced by a flaw depends on such properties as its size, shape, orientation, etc. as well as the type and extent of excitation, it becomes obvious that the result of a shearography inspection is dependent upon certain control settings, such as image shearing distance and excitation, as well as the characteristics of the flaw being inspected. As with any optical or electronic inspection method, ES results may also be influenced by noise such as unwanted light entering the optical path or random temperature variations.

It was desired that an experimental relationship be found between the output of the shearography device and the various control settings and noise levels. From this relationship, the influence of noise and control variables on the probability of detection (POD) curve was to be determined. During a NASA/ASEE summer faculty fellowship at MSFC, Dr. Enoch C. Temple of Alabama A&M University developed a statistical optimization methodology[1] to provide such analysis based upon Genichi Taguchi's method for process control, maximum likelihood analysis of variance, and response surface theory. This technique relates the values of a set of control variables, $\underline{X} = [\ x_1, x_2, ..., x_k\ ]^T$, and noise variables, $\underline{Z} = [\ z_1, z_2, ..., z_k\ ]^T$, to the instrumentation output y within an error of ε by the relationship shown in EQ.10.

$$y = B_0 + \underline{X} \cdot \underline{B} + \underline{Z} \cdot \underline{D} + \underline{X} \cdot (\underline{C}\,\underline{Z}) + \varepsilon \qquad \blacktriangleleft \text{EQ.10.} \blacktriangleright$$

Empirical values were obtained for the null response, B_0, the control influence coefficients, $\underline{B}$, the noise influence coefficients, $\underline{D}$, and the covariance matrix, $\underline{C}$, from the statistical regression analysis of a factorially designed experiment. The control variables used in this study were the image shearing distance, s, heat exposure time, h, and object distance, d. The noise variables explored here were ambient lighting, l, flaw size, a_i, and flaw orientation, r. The levels used for these variables are shown in Table 1. Table 2. indicates the combination of levels used in this study.

Table 1.   **Control and Noise Levels Investigated**

Variable Type	Variable Name	Low (-)	Medium (0)	High (+)
Control	s	0 mm	3 mm	6 mm
Control	h	5 min.		10 min.
Control	d	4 ft.		8 ft.
Noise	l	Overhead Lights Off		Overhead Lights On
Noise	a_i	3 mm	6 mm	9 mm
Noise	r	0°		45°

Table 2. **Level Combinations For Each Inspection**

i = inspection number

i	d	s	h	l	i	d	s	h	l
1	-	-	-	-	13	+	-	-	-
2	-	-	-	+	14	+	-	-	+
3	-	-	+	-	15	+	-	+	-
4	-	-	+	+	16	+	-	+	+
5	-	0	-	-	17	+	0	-	-
6	-	0	-	+	18	+	0	-	+
7	-	0	+	-	19	+	0	+	-
8	-	0	+	+	20	+	0	+	+
9	-	+	-	-	21	+	+	-	-
10	-	+	-	+	22	+	+	-	+
11	-	+	+	-	23	+	+	+	-
12	-	+	+	+	24	+	+	+	+

Variations in flaw size and orientation were incorporated into the specimen. A painted panel was prepared containing programmed unbonds of the predetermined sizes and orientations. These flaws were simulated by the presence of 0.5 mil thick aluminum foil inserts between the enamel spray paint and the D6AC steel substrate, preventing a region of controlled geometry from bonding. For repetition, the test panel contained 2 flaws of each of the 6 size/orientation combinations, as shown in Figure 83. and Table 3.
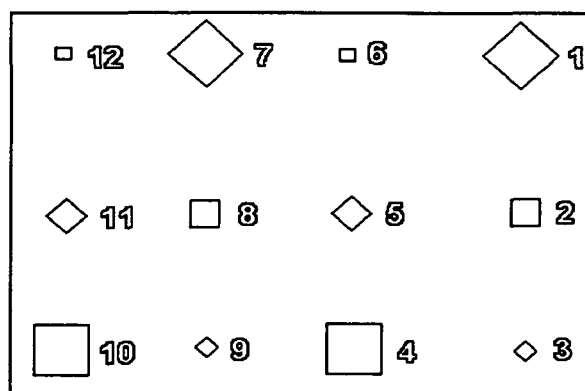
Figure 83. Arrangement of simulated unbonds on test panel.

Table 3. **Size and Orientation of Each Simulated Unbond**

FLAW NUMBER	a_i	r
1	+	+
2	0	-
3	-	+
4	+	-
5	0	+
6	-	-
7	+	+
8	0	-
9	-	+
10	+	-
11	0	+
12	-	-
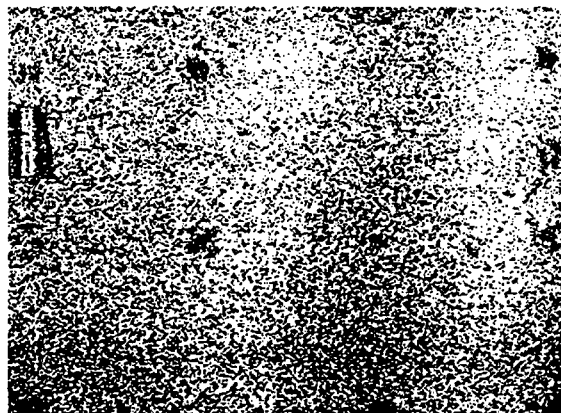
Figure 84. (N) Low level indications.
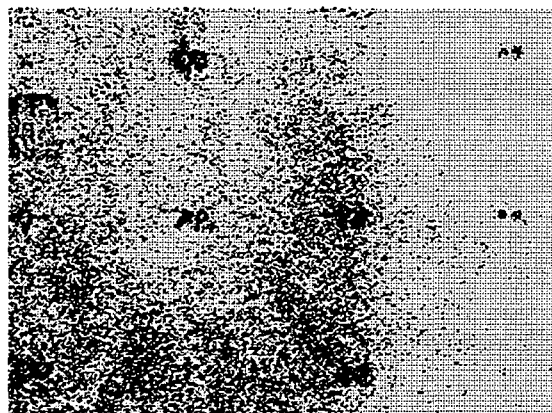
Figure 85. (N) High level indications.

The PW EH/SIS was used to conduct this experiment with thermal excitation supplied by two 500 watt halogen lamps at a distance of 6 inches from the panel. Static shearograms were recorded with four frame and speckle averaging. The reference image was recorded after the part had been exposed to excitation for the required amount of time, and this image was processed with a later image as determined by the experimenter. The detected flaws were recorded and the panel was allowed to return to room temperature before the next cycle began. Figures 84. and 85., for example, show the shearograms acquired during inspection numbers 2 and 24, respectively.

Dr. Temple's analysis based upon this experimental data indicated that, with the levels used here, ambient lighting and object distance had relatively insignificant influence upon flaw detection. A mathematical manipulation and substitution of experimental values into EQ.10., including significant terms only, gives

$$\ln\left(\frac{P_i}{1-P_i}\right) = 0.634a_ih + 0.850a_is - 4.10r + 1.86a_ir + 0.227hr \quad \text{< EQ.11. >}$$

where P_i is the average probability of detection of a flaw of size a_i. The influence coefficients of the first two terms on the right hand side of EQ.11. indicate that, for the specimen used here, the POD is maximized by using the highest level of heat and shear. The levels used here could be adopted as an inspection standard for this material system. Although the last two terms indicate that POD is increased somewhat by interactions of heating level and flaw size with a higher angle of orientation, the third term reveals that the angle of orientation generally decreases POD. Further theoretical analysis is needed to establish the means by which POD confidence may be determined, and a repetition of this experiment with more levels may be used to optimize this confidence relationship.

Since the thermo-mechanical properties of the material system and the coating thickness determine the amount of motion generated by excitation, EQ.11. is valid only for the specimens utilized here. Given that POD depends upon the material system and geometry in question, a study similar to that discussed here is necessary to establish an inspection standard for each class of test article. A generalized inspection standard cannot be relied upon for optimum performance with a variety of specimen.

APPENDICES

A.1. REFERENCES AND RELATED LITERATURE

1. Temple, E.C., "Statistical Optimization of Shearography Inspections", Final Report, NASA/ASEE Summer Faculty Fellowship Program, August 1995.

2. Russell, S.S., Lansing, M.D., Horton, C.M., Gancek, W.J., *Probability of Detection of Defects in Coatings With Electronic Shearography*, NASA Technical Memorandum 108493, June 1995.

3. Walker, J., Lansing, M.D., Russell, S.S., Workman, G.L., "Materials Characterization of Damage in Filament Wound Composite Pressure Vessels", *American Society for Nondestructive Testing (ASNT), 1995 Spring National Conference*, 20-24 March 1995.

4. Walker, J., Workman, G.L., Hill, E.v.K., Russell, S.S., "A Neural Network/Acoustic Emission Analysis of Impact Damaged Graphite/Epoxy Pressure Vessels", *American Society for Nondestructive Testing (ASNT), 1995 Spring National Conference*, 20-24 March 1995.

5. Lansing, M.D., Russell, S.S., "Shearography Detection of Unbonds in Coatings and Qualification of the Method", *American Society for Nondestructive Testing (ASNT), 1995 Spring National Conference*, 20-24 March 1995.

6. Workman, G.L., Walker, J., Lansing, M.D., *Acoustic Method of Damage Sensing in Composite Materials*, Final Report for Contract NAS8-38609, Delivery Order 99, University of Alabama in Huntsville, Center for Automation & Robotics, 20 October, 1994.

7. Maddux, G.A., Horton, C.M., Lansing, M.D., Gnacek, W.J., Newton, P.L., *Probability of Detection of Defects in Coatings with Electronic Shearography*, Technical Report No. 5-33267, University of Alabama in Huntsville, Research Institute, March 1994.

8. Maddux, G.A., Horton, C.M., McNeill, S.R., Lansing, M.D., *Field Methods to Measure Surface Displacement and Strain with the Video Image Correlation Method*, Technical Report No. 5-33282, University of Alabama in Huntsville, Research Institute, July 1994.

9. Lansing, M.D., Russell, S.S., Nettles, A., McNeill, S.R., "Video Image Correlation Strain Field Evaluation of Impact Damaged Graphite Epoxy Pressure Vessels", *American Society for Nondestructive Testing (ASNT), 1994 Spring National Conference*, 21-25 March 1994.

10. McNeill, S.R., Russell, S.S., Lansing, M.D., "Sub-pixel Digital Video Image Correlation for Full-field Strain Measurement", approved by *NASA TechBriefs* January, 1994 (pending publication).

11. Durig, B., Zhang, F., McNeill, S.R., Chao, Y.J., Peters, W.H., "A Study of Mixed Mode Fracture by Photoelasticity and Digital Image Analysis", *Optics and Lasers in Engineering, Vol. 14*, 1991.

12. Maji, A.K., Wang, J.L., Lovato, J., "Electronic Speckle Pattern Interferometry for Fracture Mechanics Testing", *Experimental Techniques*, May/June 1991.

13. Dally, J.W., Riley, W.F., *Experimental Stress Analysis*, McGraw-Hill, Inc., 1991.

14. Newman, J.W., "Inspection of Aircraft Structure with Advanced Shearography", *American Society for Nondestructive Testing (ASNT), 1990 Fall National Conference*, 10 October 1990.

15.   Parsi, F., Husband, D.M., Lisk, J.S., Gadala-Maria, F., McNeill, S.R., Sutton, M.A., "Application of Digital Image Processing to the Analysis of Two Phase Materials with Spherical Inclusions", *Polymer Composites, Vol. 11*, June 1990.

16.   Bruck, H.A., McNeill, S.R., Sutton, M.A., Peters, W.H., "Digital Image Correlation Using Newton-Raphson Method of Partial Differential Correction", *Experimental Mechanics*, September 1989.

17.   Bruck, H.A., McNeill, S.R., Russell, S.S., Sutton, M.A., "Use of Digital Image Correlation for Determination of Displacements and Strains", *Nondestructive Testing Monographs and Tracts, Volume 5: Nondestructive Evaluation for Aerospace Requirements*, 1989.

18.   Sutton, M.A., McNeill, S.R., Jang, J., Babai, M., "Effects of Subpixel Image Restoration on Digital Correlation Estimates", *Optical Engineering*, October 1988.

19.   Broek, D., *Elementary Engineering Fracture Mechanics*, Martinus Nijhoff Publishers, 1987.

20.   McNeill, S.R., Peters, W.H., Sutton, M.A., "Estimation of Stress Intensity Factor by Digital Image Correlation", *Engineering Fracture Mechanics*, Vol. 28, No. 1.

21.   Sutton, M.A., Cheng, M., Peters, W.H., Chao, Y.J., McNeill, S.R., "Application of an Optimized Digital Correlation Method to Planar Deformation Analysis", *Image and Vision Computing*, August 1986.

22.   Mohanty, R.K., Joenathan, C., Sirohi, R.S., "High Sensitivity Tilt Measurement by Speckle Shear Interferometry", *Applied Optics, Vol. 25, No. 10*, 15 May 1986.

23.   Mohanty, R.K., Joenathan, C., Sirohi, R.S., "Speckle and Speckle-shearing Interferometers Combined for the Stimultaneous [sic] Determination of Out-of-plane Displacement and Slope", *Applied Optics, Vol. 24, No. 18*, 15 September 1985.

24.   Sutton, M.A., Wolters, W.J., Peters, W.H., Ranson, W.F., McNeill, S.R., "Determination of Displacements Using an Improved Digital Correlation Method", *Computer Vision*, August 1983.

25.   Hung, Y.Y., "Shearography: A New Optical Method for Strain Measurement and Nondestructive Testing", *Optical Engineering, Vol. 21, No. 3*, May/June 1982.

26.   Boone, P.M., "Determination of Slope and Strain Contours by Double-exposure Shearing Interferometry", *Experimental Mechanics*, August 1975.

A.2. FWPV DATA

A.2.1. GRAPHITE-EPOXY

A.2.1.1. EMPTY Gr-Ep CASES

3501-ATL Resin

A001-002

0.01100   0.01400   0.03900

A009-010

-0.01000   0.00550   0.02100

A011-012

-0.00400   0.00350   0.01100

A015-016

-0.01400   0.00300   0.02000
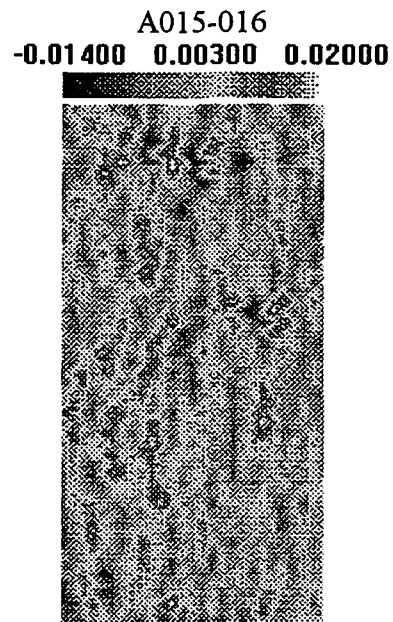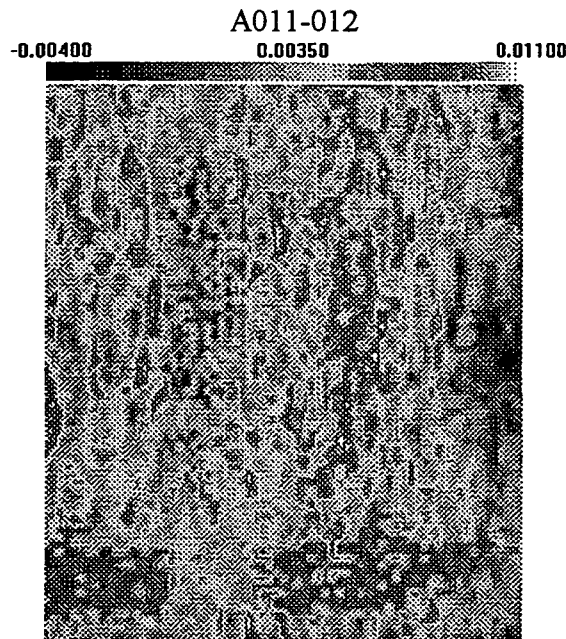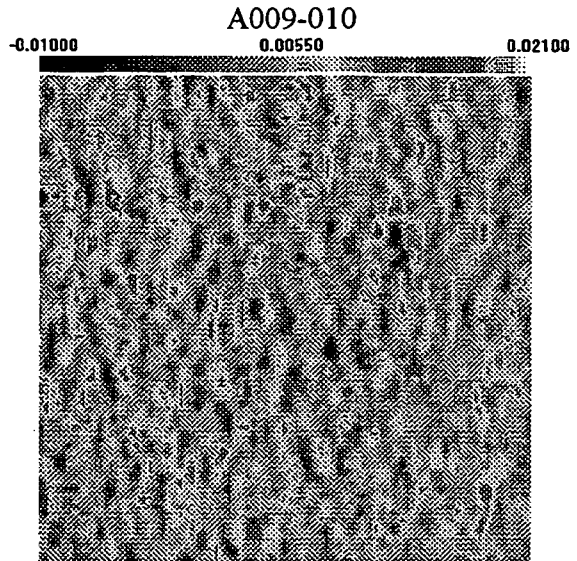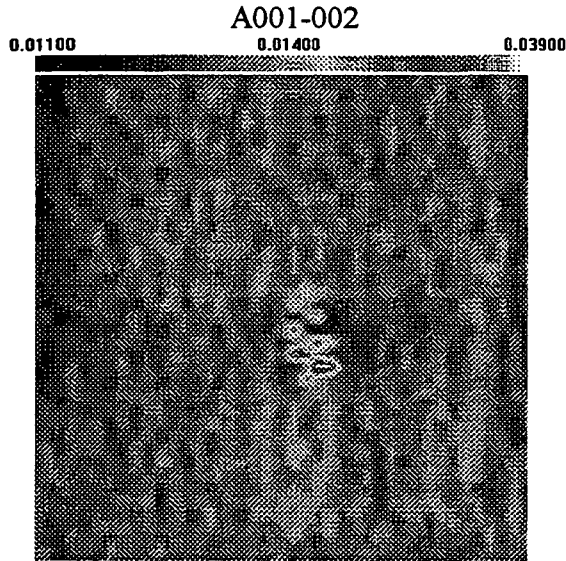
A019-020
-0.00400   0.00400   0.01200
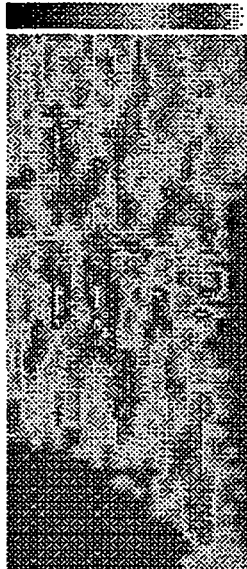
A021-022
-0.00300   0.00450   0.01200
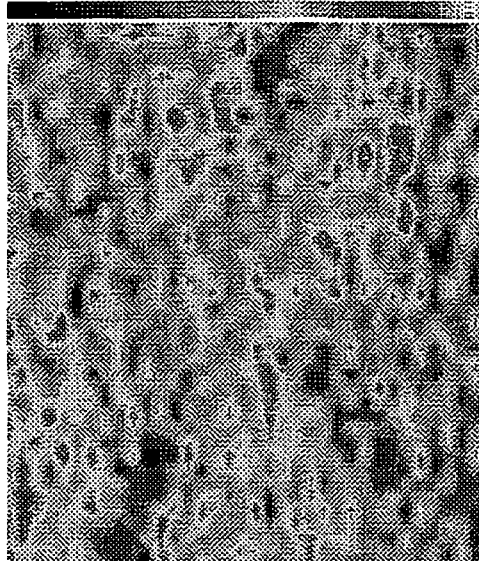
C075-076
-0.00400   0.00400   0.01200

C081-082
-0.02200   0.00200   0.02600
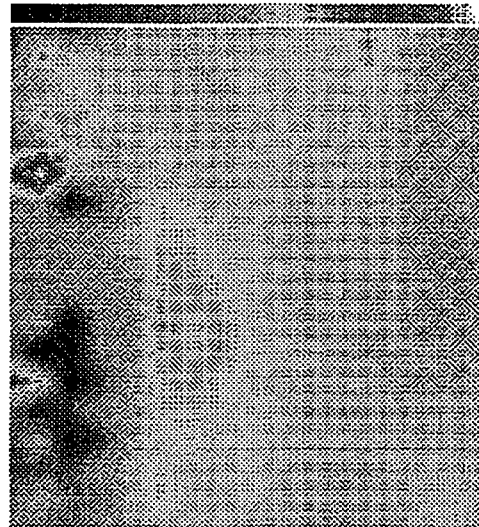
C083-084
-0.00500   0.00300   0.01100
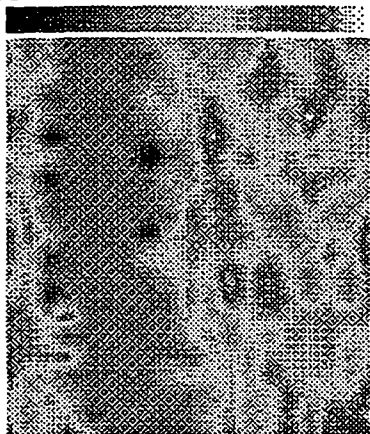
C085-086
-0.00200   0.00550   0.01300

8553-6 Resin

A031-032

-0.00600 0.00400 0.01400

A037-038

-0.00900 0.02050 0.05000

A039-040

-0.00500 0.00350 0.01200

A041-042

-0.00800 0.02950 0.06700
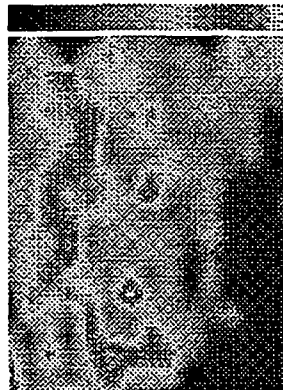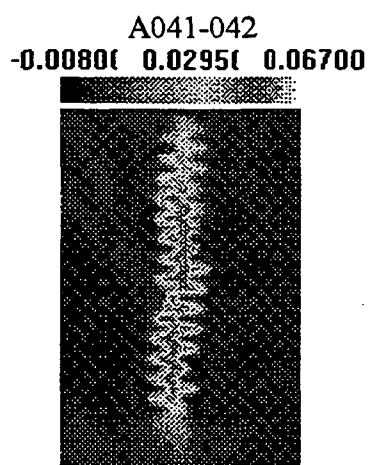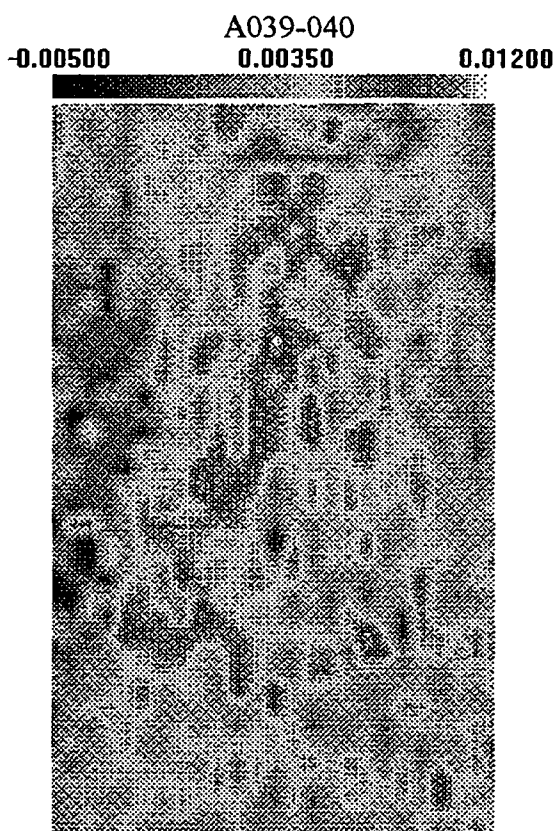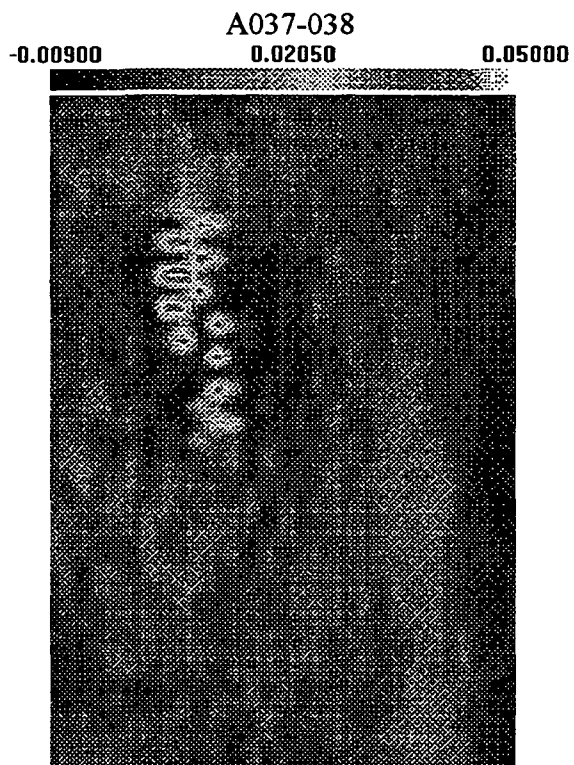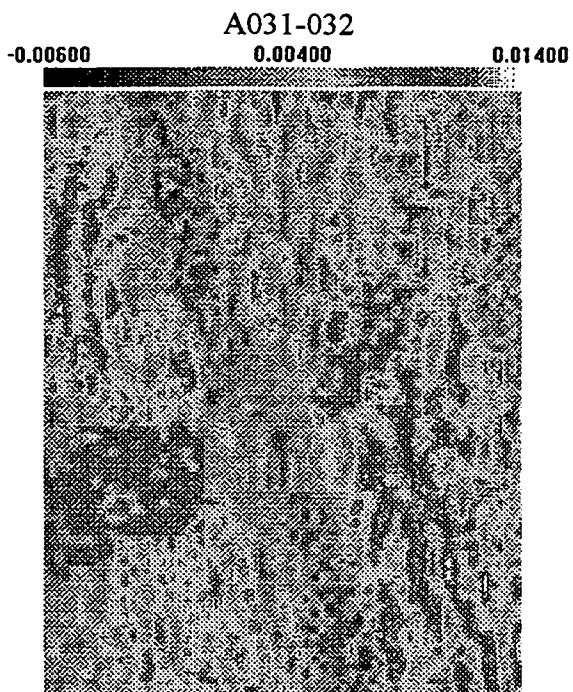
C097-098
-0.00300   0.00550   0.01400

C101-102
-0.00500   0.00450   0.01400
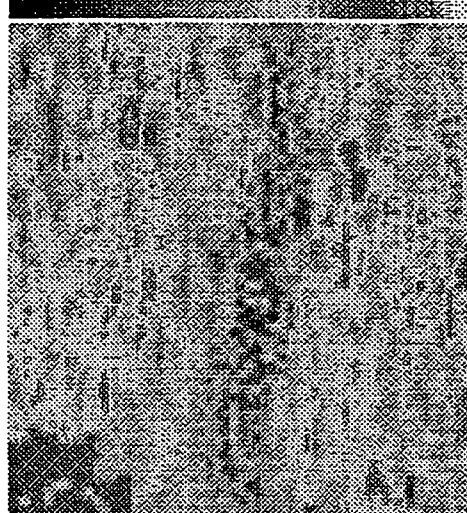
C103-104
-0.01600   0.02500   0.06600
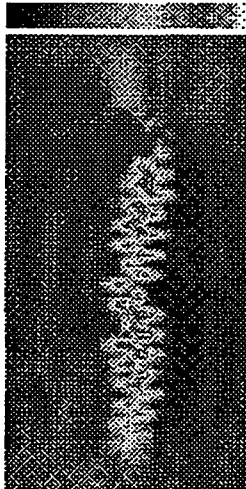
C105-106
-0.01100   0.03050   0.07200

977-2 Resin

C111-112

-0.00400 0.00450 0.01300

C121-122

-0.00300 0.00500 0.01300

C123-124

-0.02200 0.03200 0.08600

C133-134

-0.00500 0.00500 0.01500
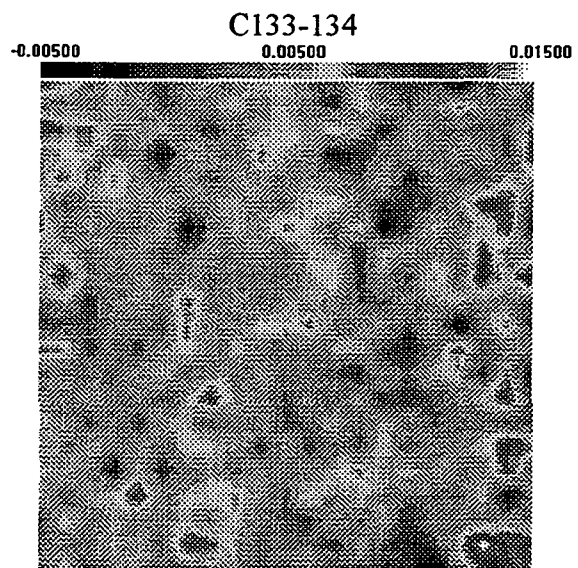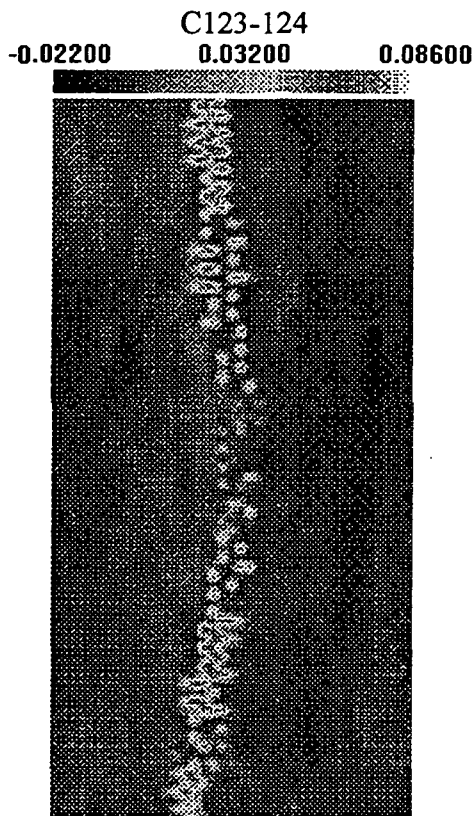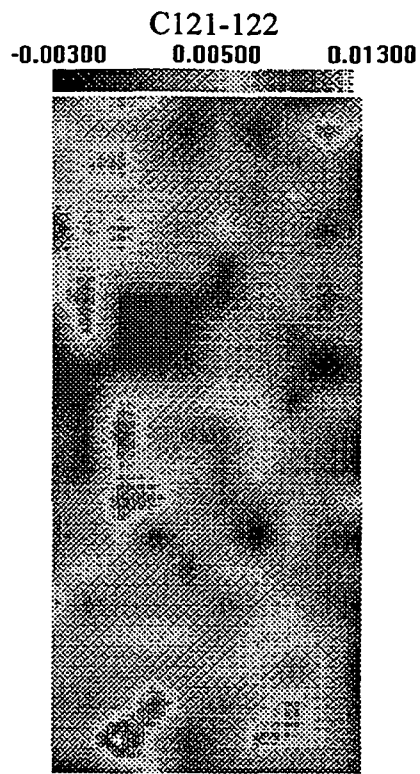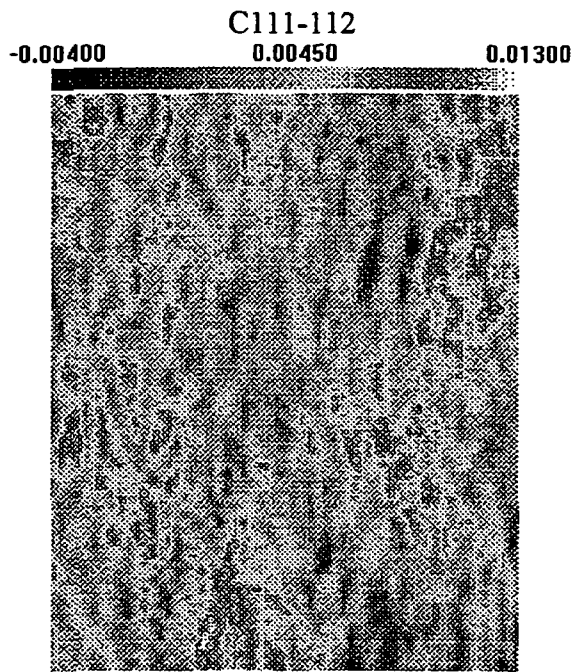
C145-146
-0.00100   0.00450   0.01000
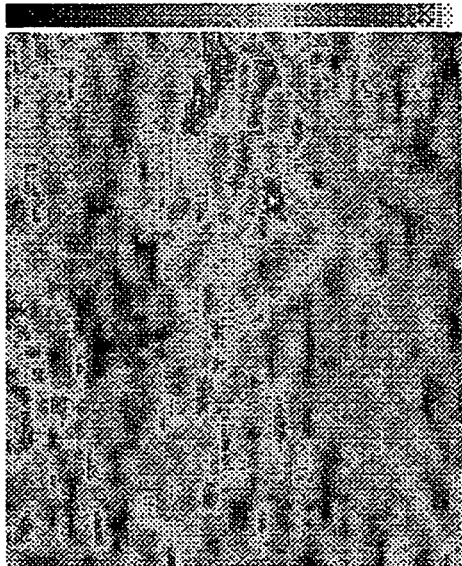
C147-148
-0.00400   0.00450   0.01300
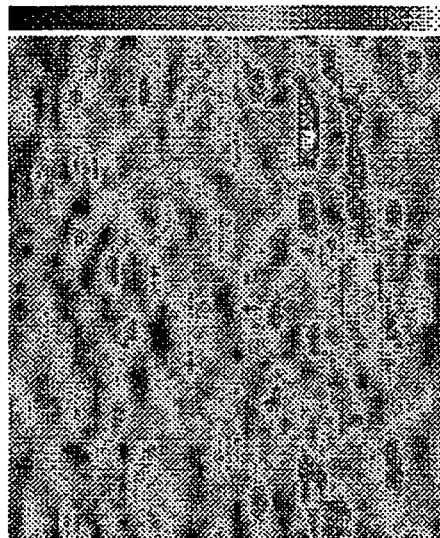
C149-150
-0.00500   0.00450   0.01400

C153-154
-0.00400   0.00600   0.01600
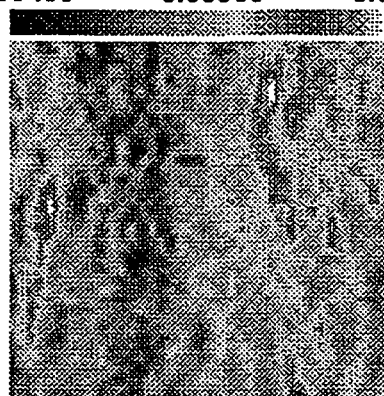
C157-158

-0.00200   0.00400   0.01000
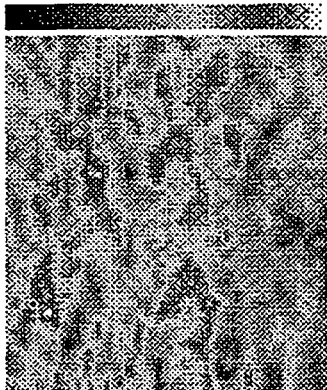
A.2.1.2. Gr-Ep CASES FILLED WITH INERT PROPELLANT

3501-6 ATL Resin

A003-004	No Impact	No Impact	2639 psi
-0.0060 0.0005 0.00700	-0.0020 0.0025 0.00700	-0.0070 0.0055 0.01800	-0.0010 0.0055 0.01200

250 psi   500 psi   750 psi   1000 psi

c069-070	Blunt Tip	Low Energy	2279 psi
-0.0070 0.0005 0.00800	-0.0070 0.0030 0.01300	-0.0040 0.0030 0.01000	-0.0030 0.0045 0.01200

250 psi   500 psi   750 psi   1000 psi

58
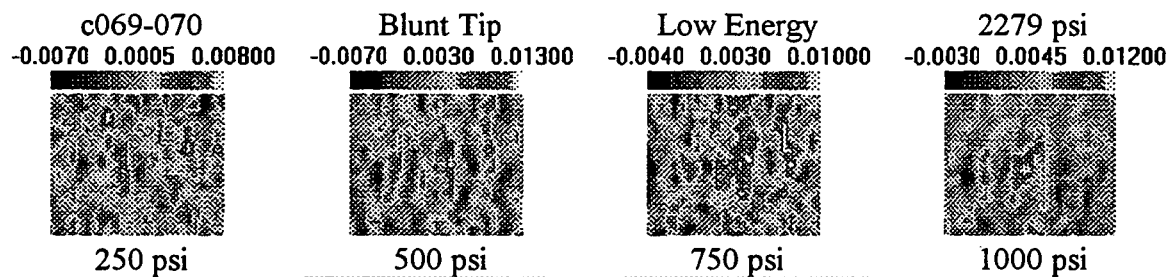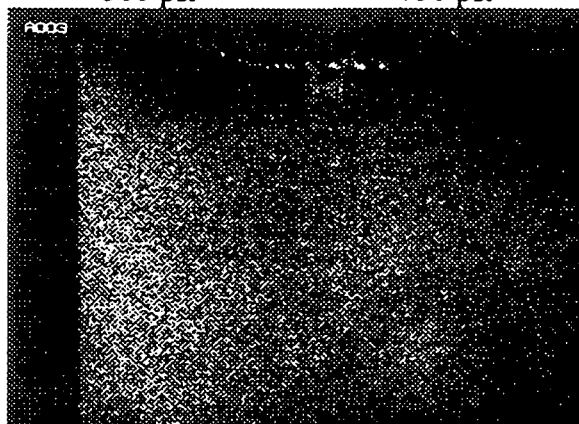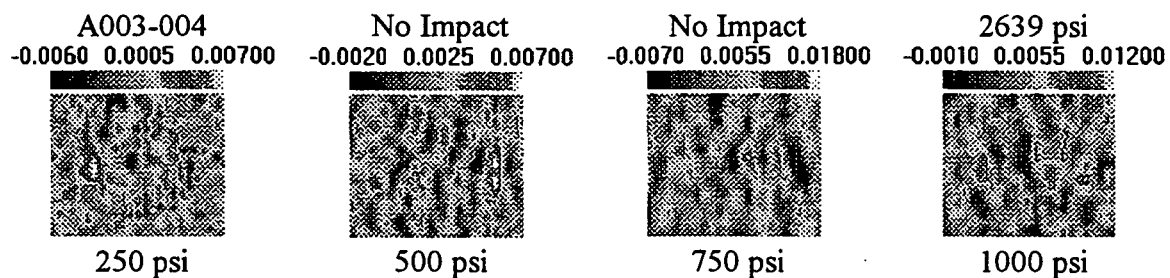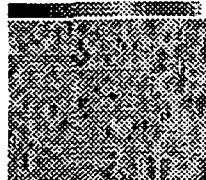
C077-078   Blunt Tip   High Energy   2373 psi
-0.00800 0.00100 0.01000   -0.00300 0.00200 0.00700   -0.00500 0.00350 0.01200   -0.00400 0.00450 0.01300
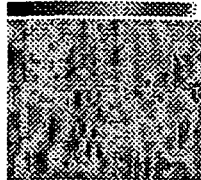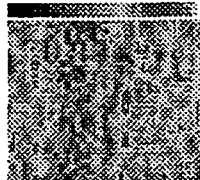
250 psi   500 psi   750 psi   1000 psi
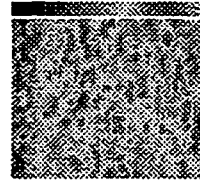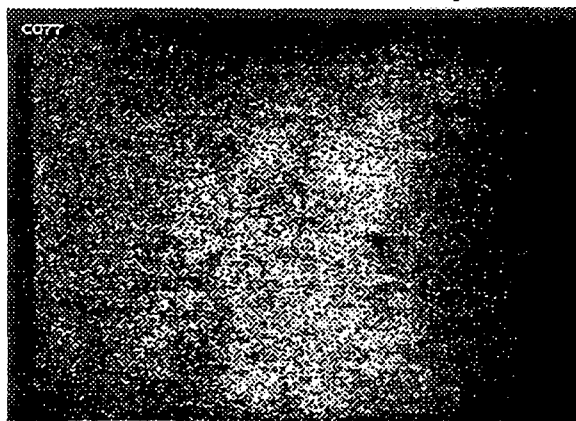
A013-014   Sharp Tip   Low Energy   2232 psi
-0.0040 0.0005 0.00500   -0.0050 0.0035 0.01200   -0.0020 0.0070 0.01600   -0.0020 0.0115 0.02500
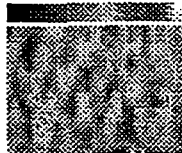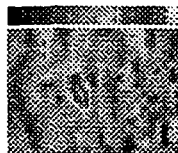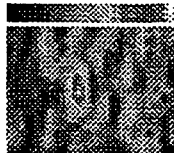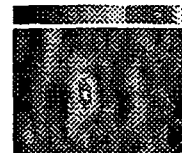
250 psi   500 psi   750 psi   1000 psi

A023-024

-0.00800 0.00250 0.01300   -0.00900 0.01000 0.02900   -0.00800 0.01300 0.03400   -0.01200 0.01900 0.05000
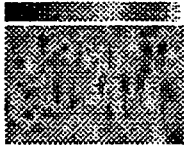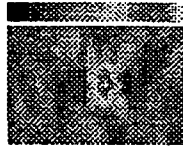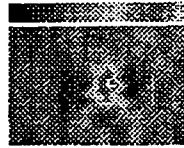
Sharp Tip   High Energy   2266 psi

250 psi   500 psi   750 psi   1000 psi

A017-018   Sharp Tip   High Energy
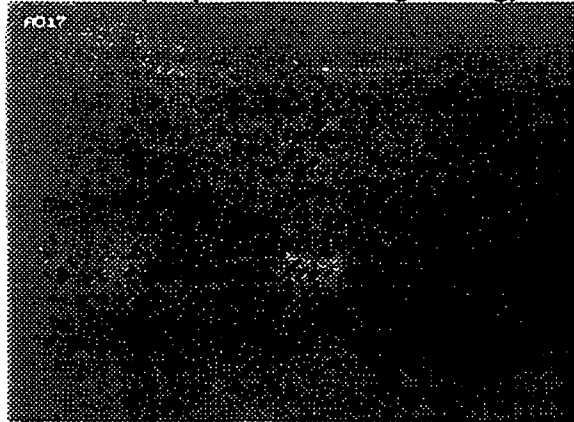
X8553-45 Resin

A025-026	No Impact	No Impact	3171 psi
-0.0050 0.0020 0.00900	-0.0030 0.0020 0.00700	-0.0040 0.0045 0.01300	-0.0030 0.0040 0.01100

250 psi	500 psi	750 psi	1000 psi
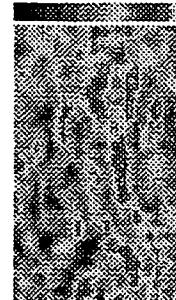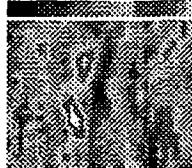
A029-030	Blunt Tip	Low Energy	2302 psi
-0.00600 0.00250 0.01100	-0.00500 0.01150 0.02800	-0.00300 0.01000 0.02300	-0.00700 0.01800 0.04300
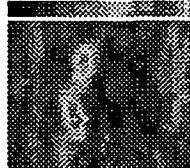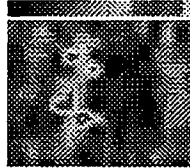
250 psi	500 psi	750 psi	1000 psi
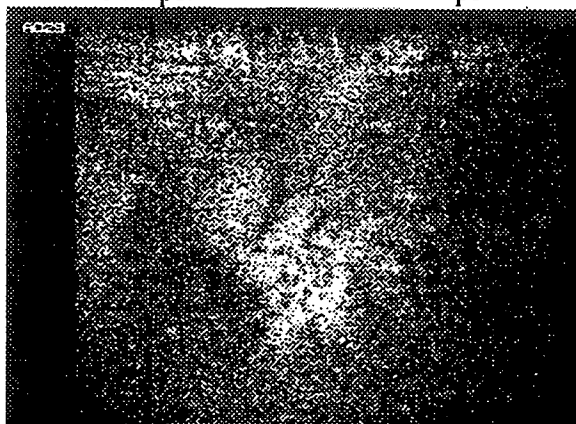
A047-048
-0.00300   0.00150   0.00600
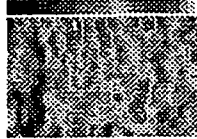
Blunt Tip
-0.00300   0.00450   0.01200

High Energy
-0.00100   0.00650   0.01400

2463 psi
-0.00200   0.00900   0.02000

250 psi

500 psi
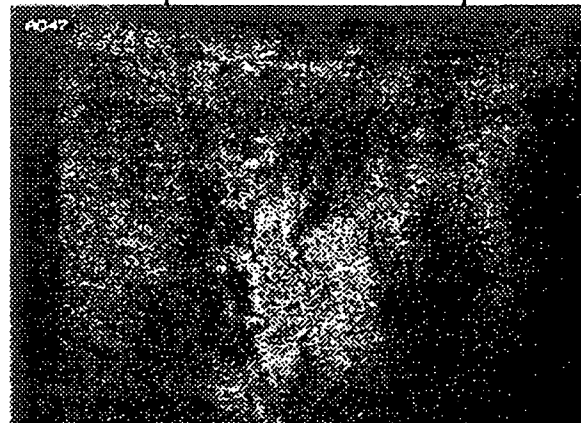
750 psi

1000 psi

C087-088
-0.0060   0.0010   0.00800
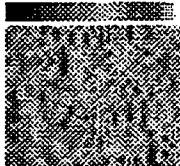
Sharp Tip
-0.0090   0.0035   0.01600
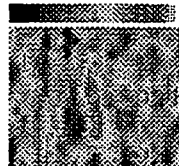
Low Energy
-0.0110   0.0035   0.01800
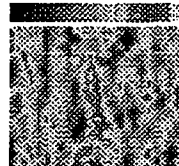
2489 psi
-0.0080   0.0090   0.02600
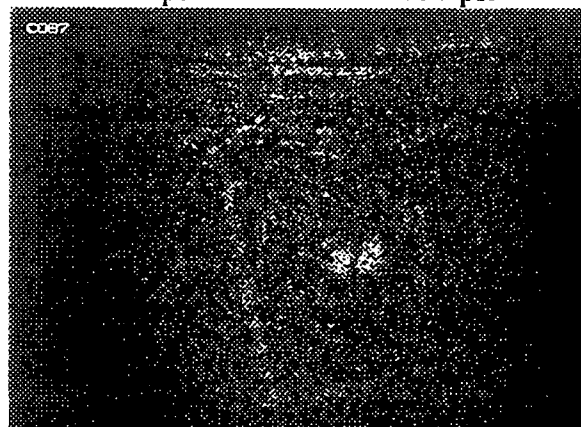
250 psi

500 psi

750 psi

1000 psi

C-093-094	Sharp Tip	High Energy	1995 psi
-0.0060 0.0030 0.01200	-0.0060 0.0135 0.03300	-0.0070 0.0185 0.04400	-0.0100 0.0250 0.06000
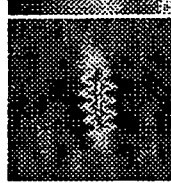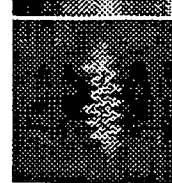
250 psi	500 psi	750 psi	1000 psi

977-2 Resin

C-115-116	No Impact	No Impact	3335 psi
-0.00E 0.000 0.00B00	-0.00E 0.001 0.01200	-0.013 0.003 0.01900	-0.011 0.00B 0.02700

| 250 psi | 500 psi | 750 psi | 1000 psi |

C141-142	Blunt Tip	Low Energy	2786 psi
-0.0040 0.0010 0.00600	-0.0170 0.0020 0.02100	-0.0170 0.0025 0.02200	-0.0160 0.0080 0.03200
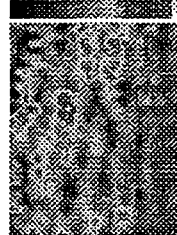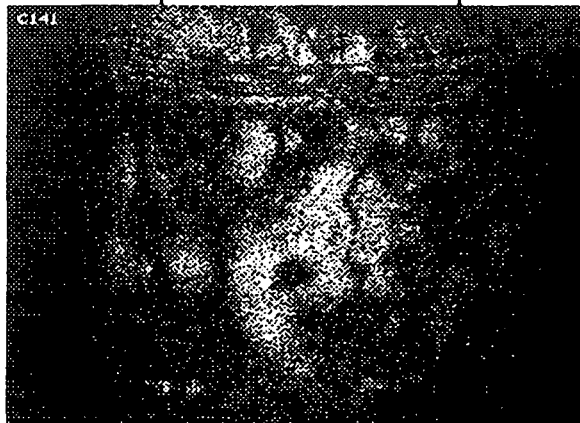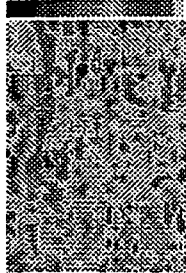
| 250 psi | 500 psi | 750 psi | 1000 psi |

C155-156	Sharp Tip	High Energy	2804 psi
-0.00E 0.000 0.00800	-0.00E 0.003 0.01200	-0.001 0.005 0.01200	-0.00E 0.006 0.01800
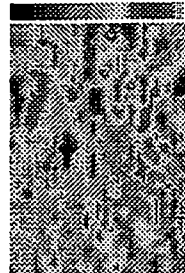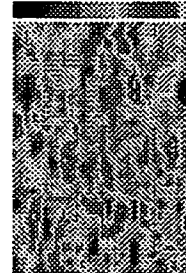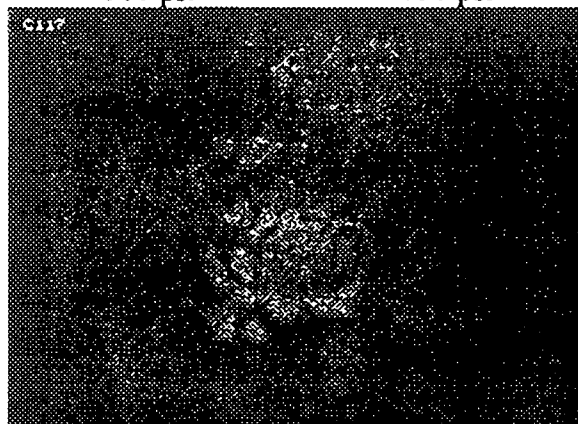
250 psi	500 psi	750 psi	1000 psi

A.2.2. KEVLAR-EPOXY

A.2.2.1. EMPTY K-Ep CASES

D161-162　　　　Unknown Impact　　　　　2249 psi
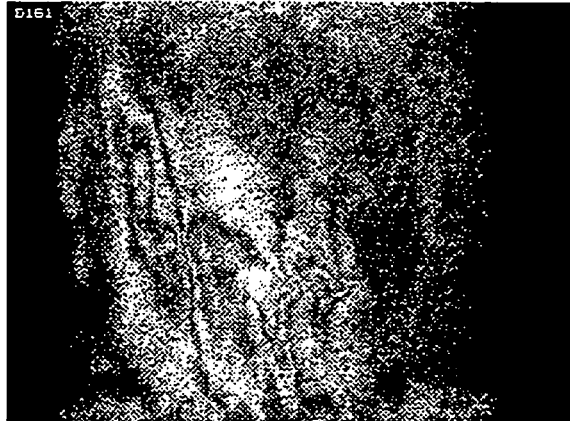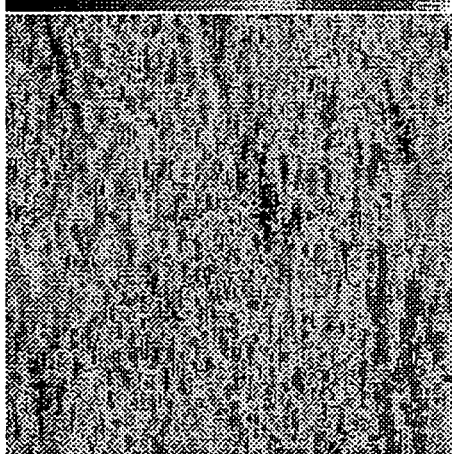
D163-164　　　　Blunt Tip　　10.90 ft-lb　　2194 psi
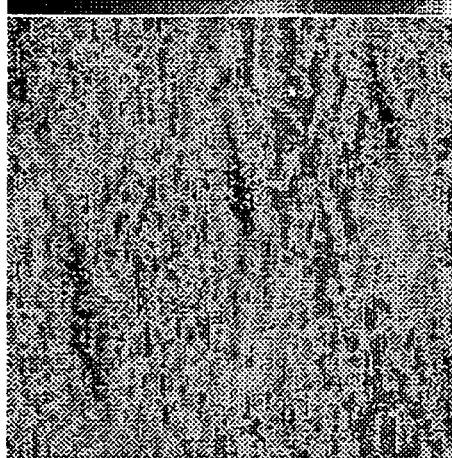
D165-166 Sharp Tip 7.00 ft-lb 2353 psi
-0.00500 0.00600 0.01700
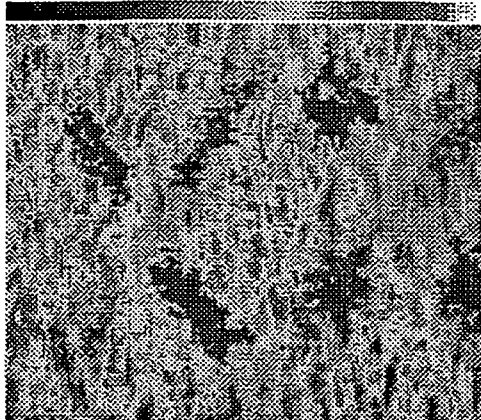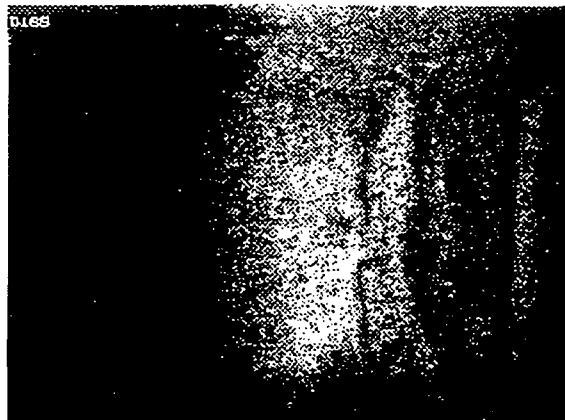
D169-170 Sharp Tip 8.83 ft-lb 2608 psi
-0.01400 0.00450 0.02300
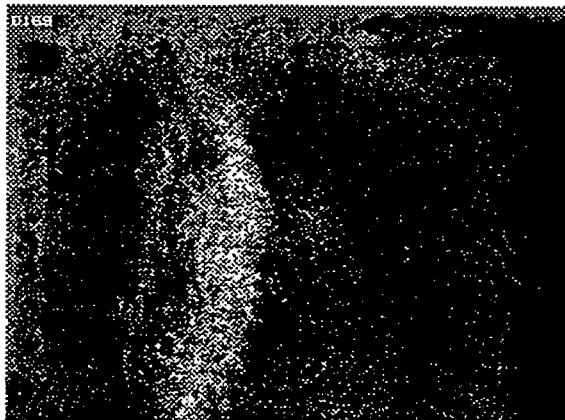
D177-178 Sharp Tip 11.91 ft-lb 2237 psi
-0.01200 0.00750 0.02700
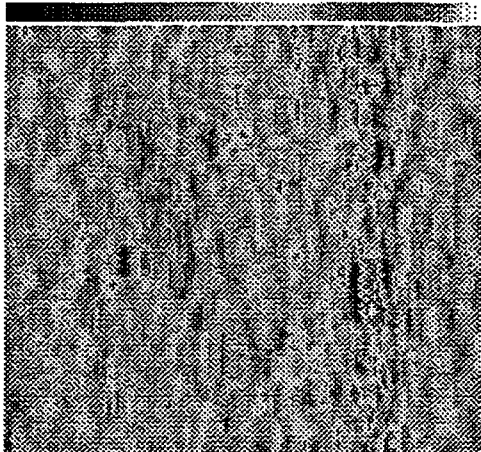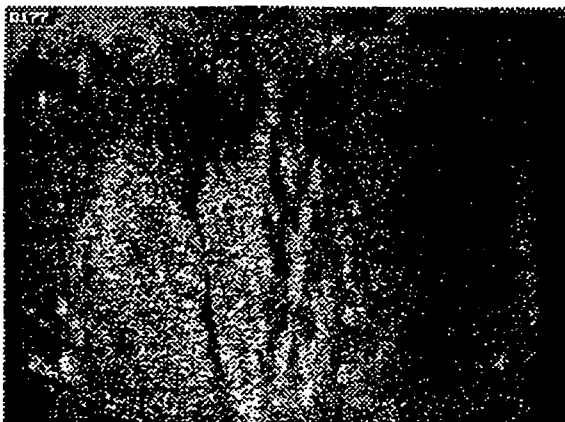
D179-180   Sharp Tip   10.00 ft-lb   2561 psi
-0.00500   0.00650   0.01800
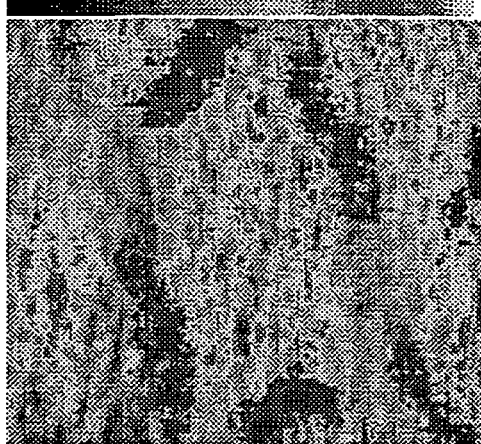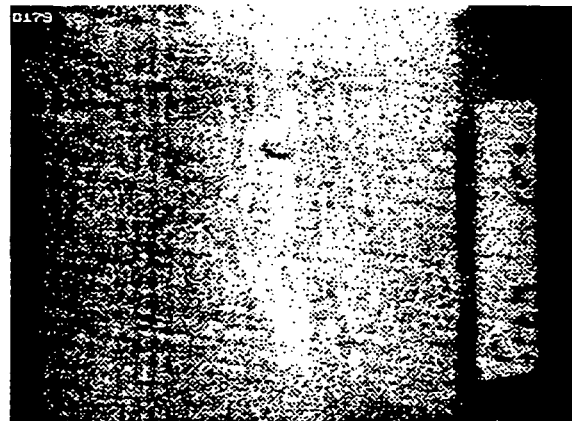
D187-188   Blunt Tip   11.80 ft-lb   2407 psi
-0.01000   0.00950   0.02900
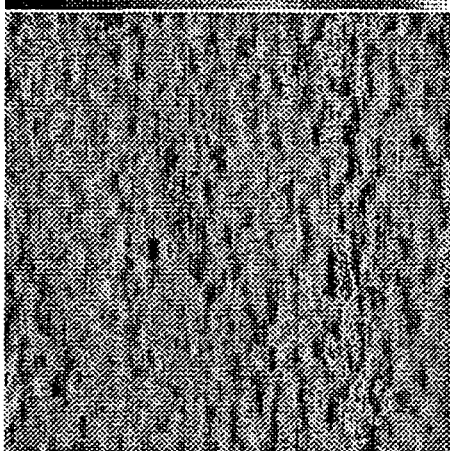
D201-202   Sharp Tip   6.90 ft-lb   2597 psi
-0.00600   0.00550   0.01700
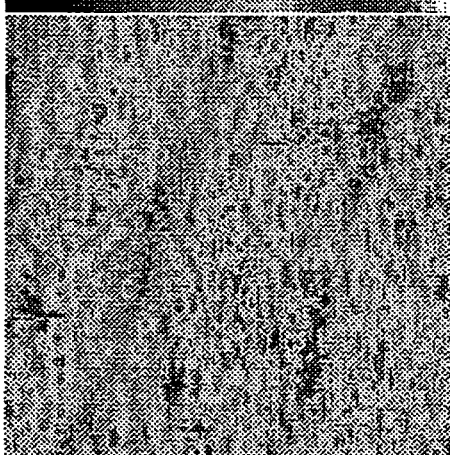
D213-214   Sharp Tip   11.00 ft-lb   2356 psi
-0.01200   0.00350   0.01900
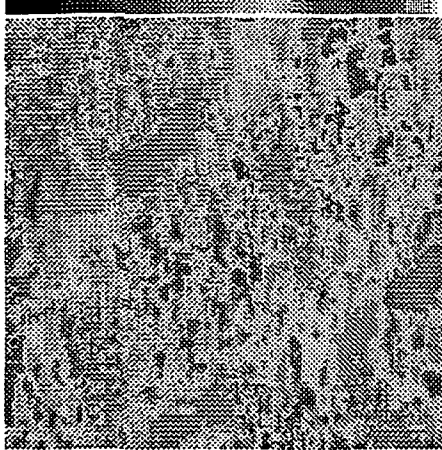
SHEAROGRAM NOT AVAILIBLE.

D215-216   Sharp Tip   7.10 ft-lb   2503 psi
-0.00300   0.00600   0.01500
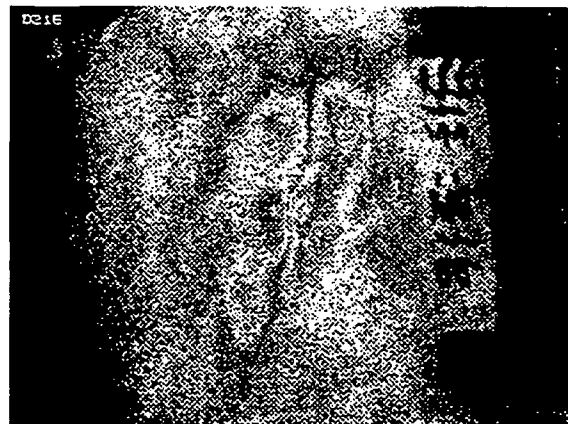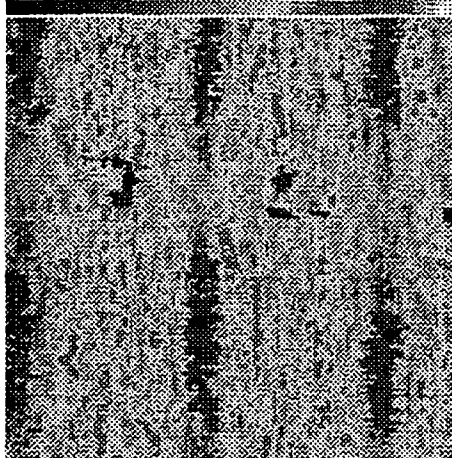
D221-222   No Impact   No Impact   2867 psi
-0.00200   0.00600   0.01400
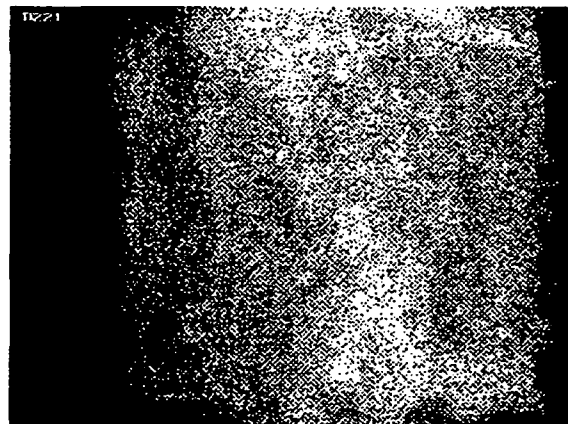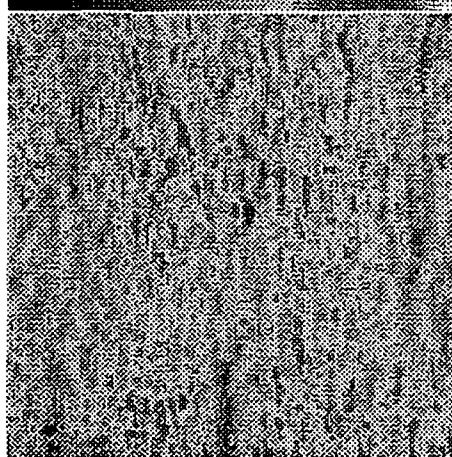
D225-226 Sharp Tip 11.80 ft-lb 2149 psi
-0.01000 0.00850 0.02700
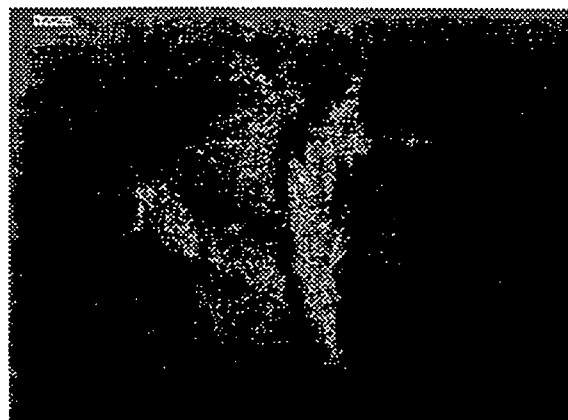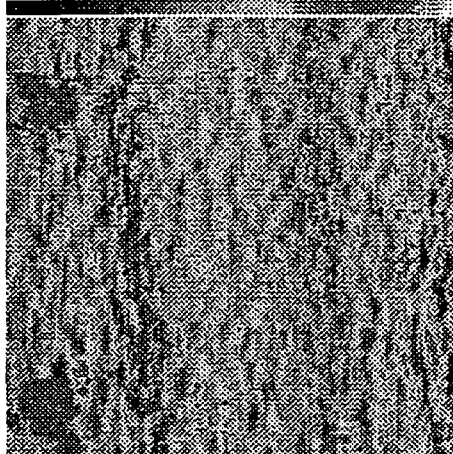
D227-228 Blunt Tip 12.00 ft-lb 2275 psi
-0.00900 0.00600 0.0210
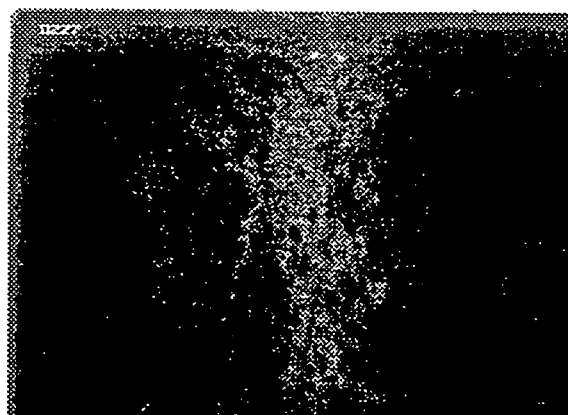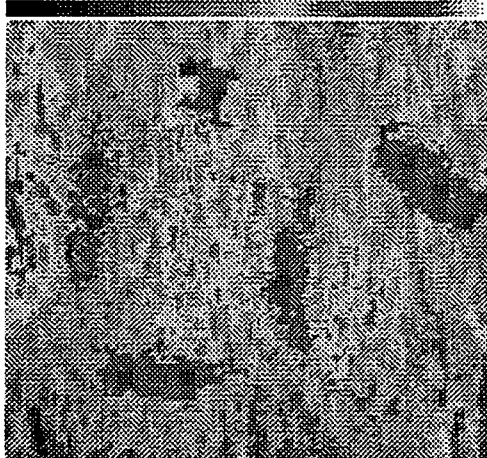
D233-234 No Impact No Impact 3057 psi
-0.00400 0.00550 0.01500
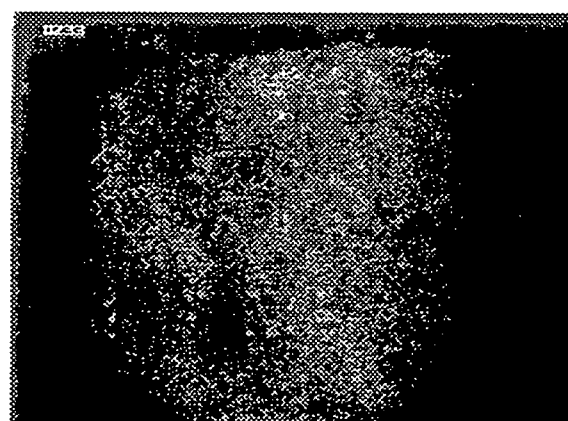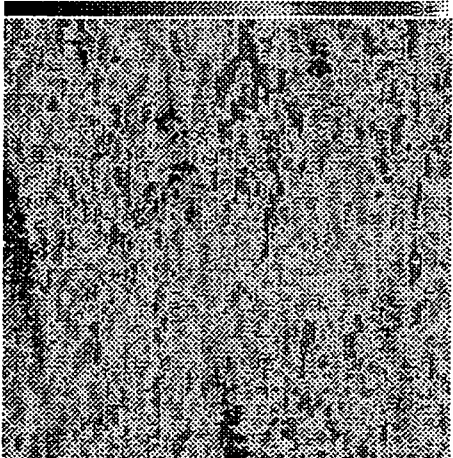
D235-236   Blunt Tip   14.41 Ft.Lbs.   1701 psi

-0.03600   0.00250   0.04100
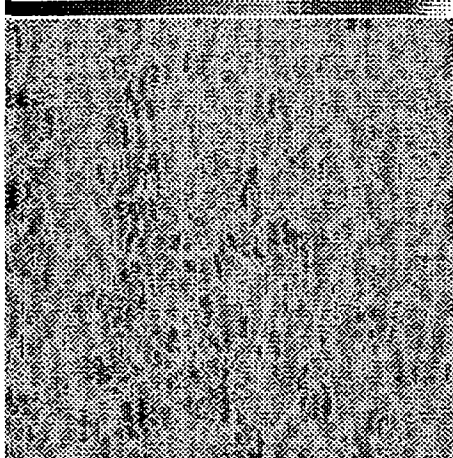
D237-238   Sharp Tip   9.80 ft-lb   2314 psi

-0.00300   0.00800   0.01900
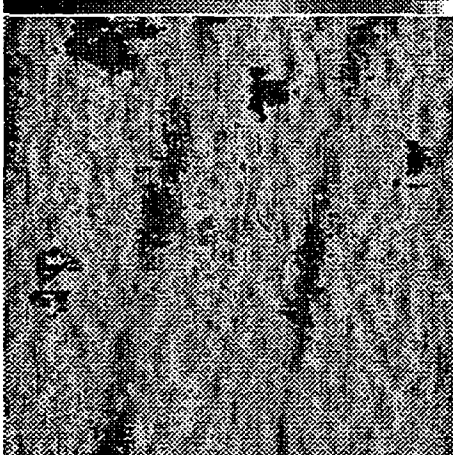
D239-240   Blunt Tip   15.50 ft-lb   1796 psi

-0.00500   0.00550   0.01600
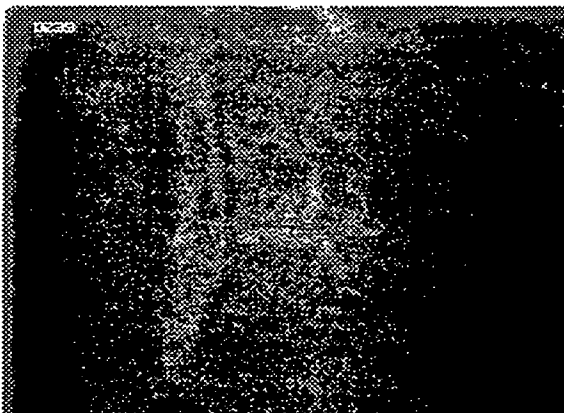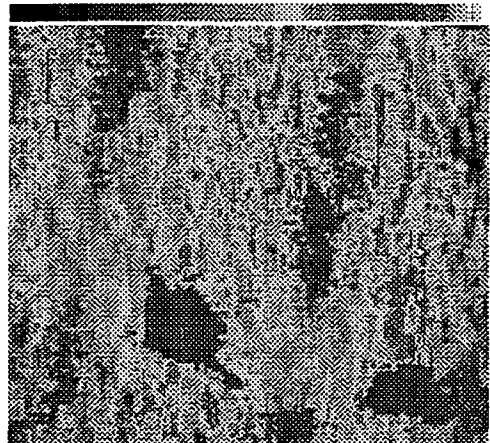
D241-242   Blunt Tip   9.00 ft-lb   2354 psi

-0.00700   0.00600   0.01900
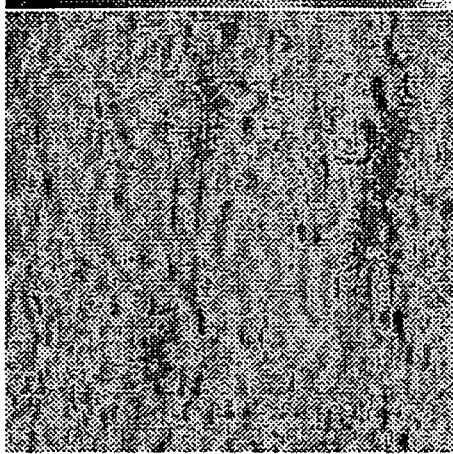
D253-254   Blunt Tip   13.09 & 14.41 ft-lb   1541 psi

-0.01400   0.00750   0.02900
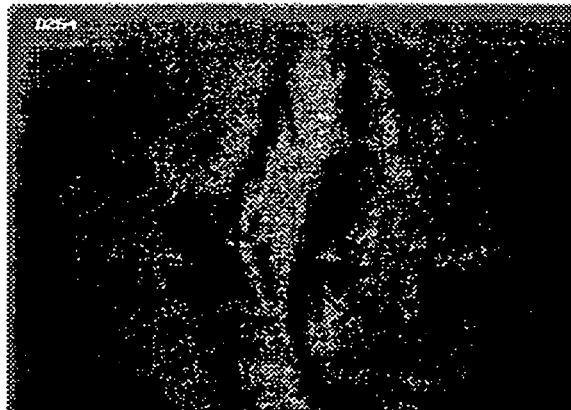
A.2.2.2. K-Ep CASES FILLED WITH INERT PROPELLANT

D175-176   Blunt Tip   16.5 ft-lb   1997 psi
-0.00400   0.00650   0.01700
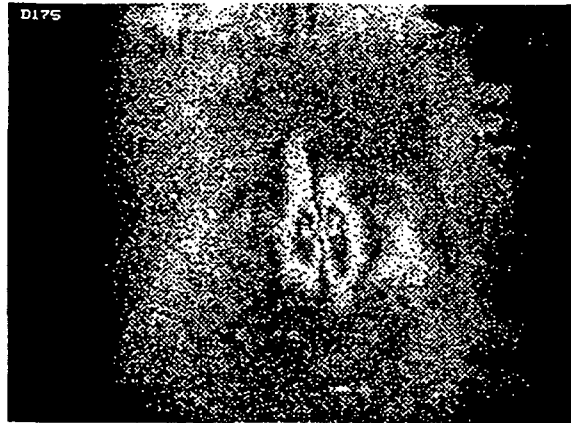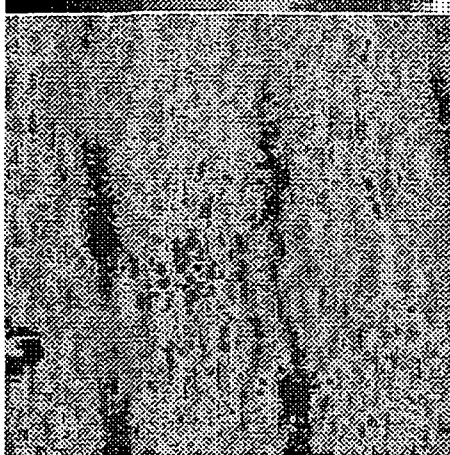
D181-182   Sharp Tip   2.89 ft-lb   2390 psi
-0.01600   0.00600   0.02800
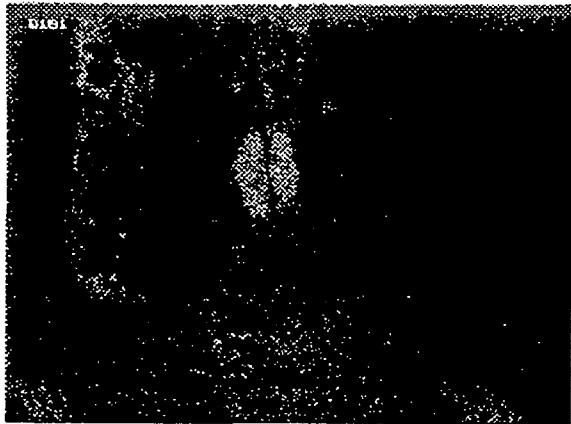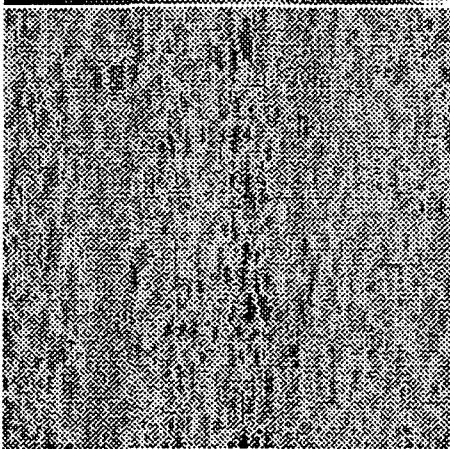
D185-186   No Impact   No Impact   3025 psi
0.00000   0.00650   0.01300
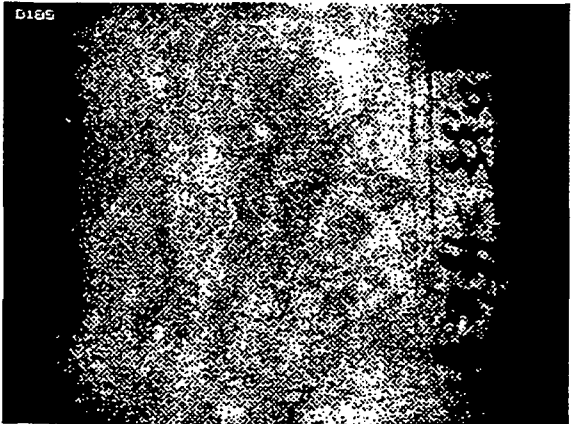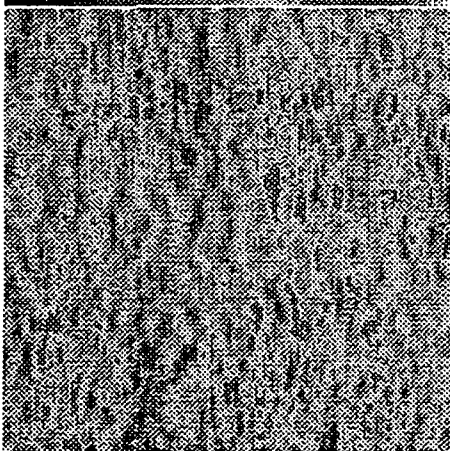
D191-192 Blunt Tip 20.28 ft-lb 2099 psi

SDVIC RESULTS NOT AVAILIBLE.

Boss leak prevented image acquisition.
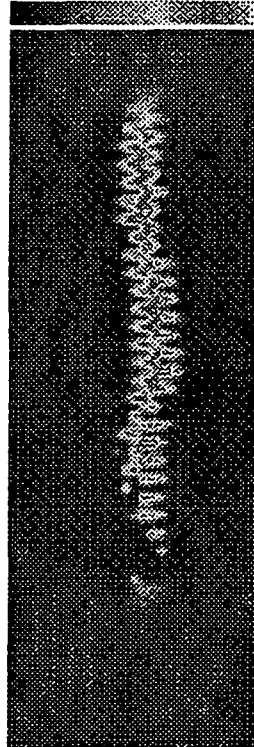
D197-198 Sharp Tip 4.23 ft-lb 2319 psi
-0.00600 0.00700 0.02000
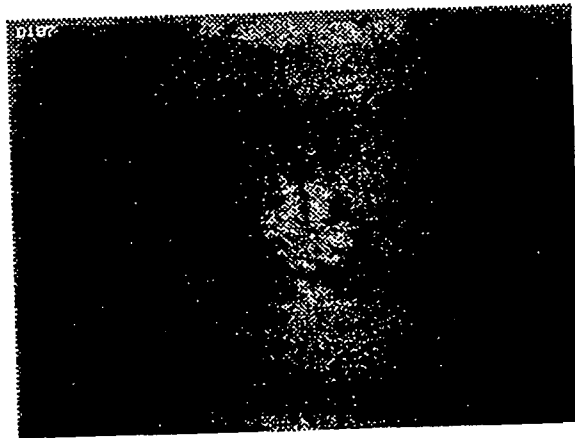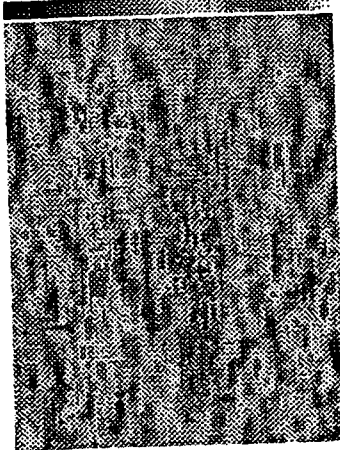
D205-206 Blunt Tip 4.95 ft-lb 3071 psi
-0.00500 0.00450 0.01400
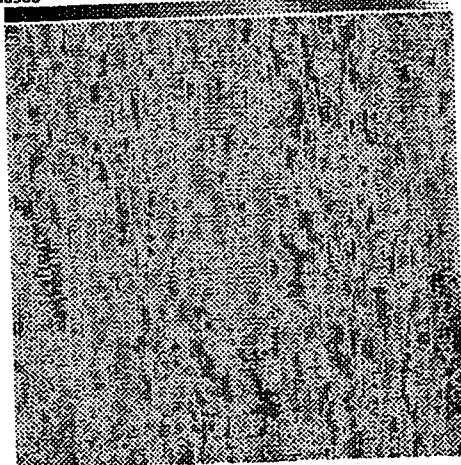
D223-224 No Impact

No Impact 2978 psi

-0.00700 0.00600 0.01900
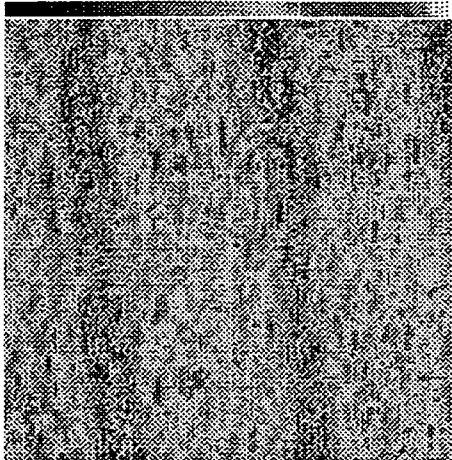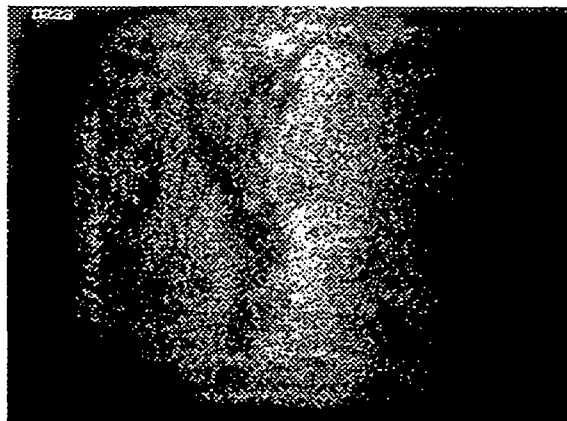
D229-230 Blunt Tip

17.00 ft-lb 2196 psi

-0.00800 0.00350 0.01500
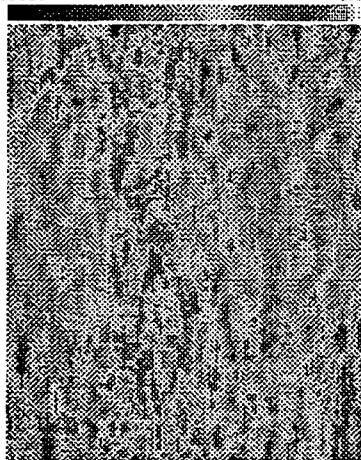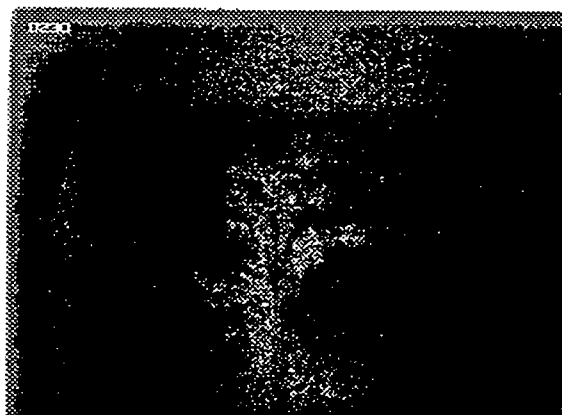
D231-232 Sharp Tip

4.85 ft-lb 2072 psi

SDVIC RESULTS NOT AVAILIBLE.

Bottle leak prevented image acquisition.

D243-244 Sharp Tip 2.17 ft-lb · 2588 psi
-0.00600 0.00600 0.0180
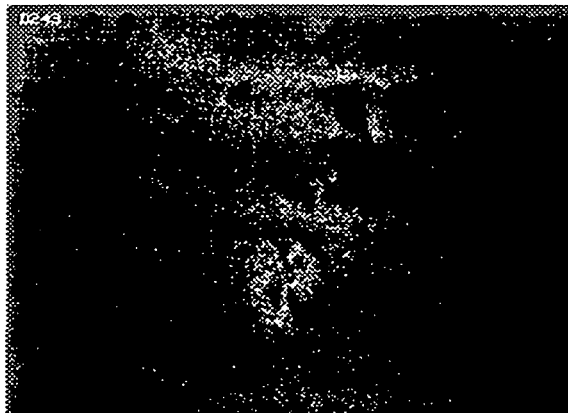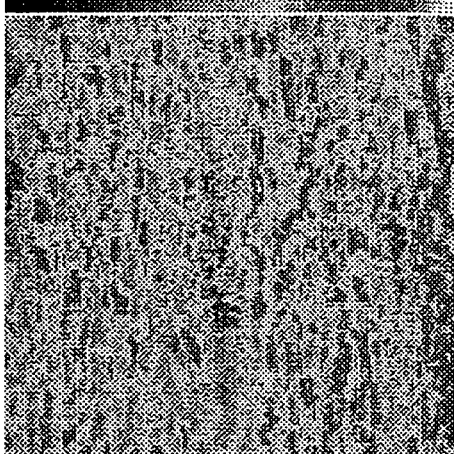
D245-246 Blunt Tip 13.29 ft-lb 2249 psi
-0.00500 0.00450 0.01400
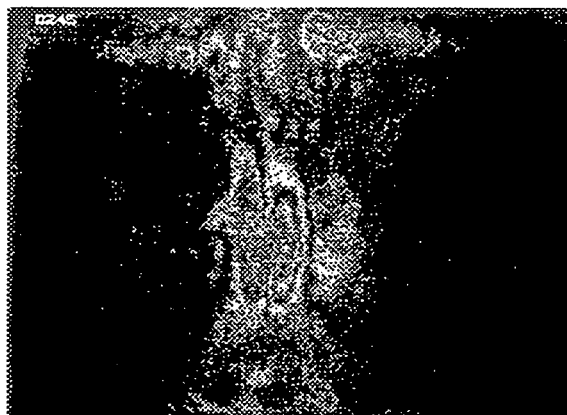
D247-248 Blunt Tip 10.90 ft-lb 2541 psi
-0.00700 0.00400 0.01500
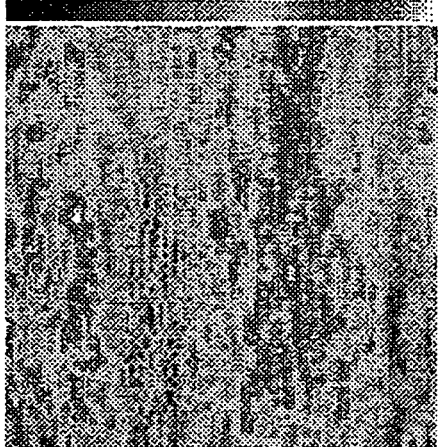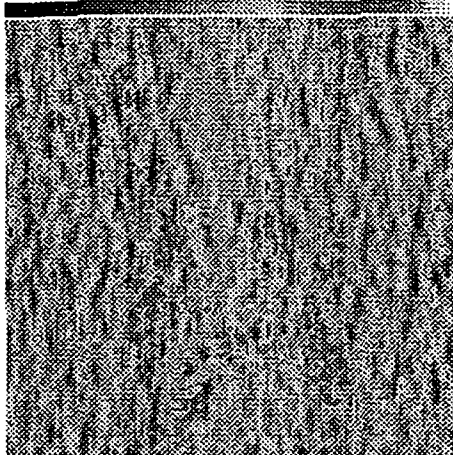
D249-250   Sharp Tip   3.82 ft-lb   2560 psi
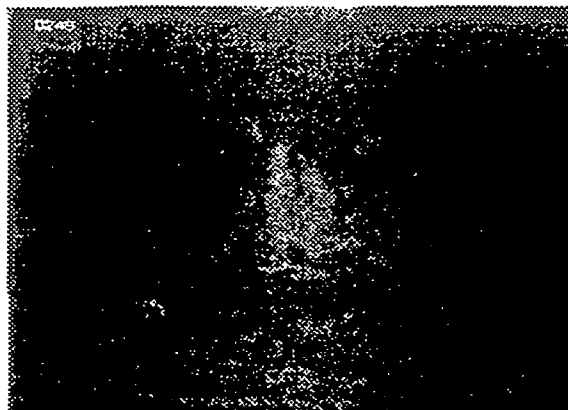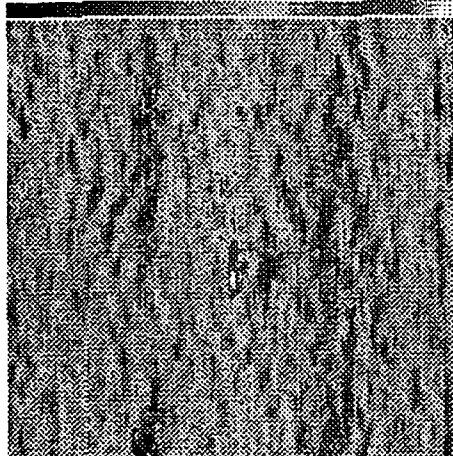
D255-256   Sharp Tip   4.1 ft-lb   2682 psi

D257-258   Blunt Tip   10.90 ft-lb   N/A
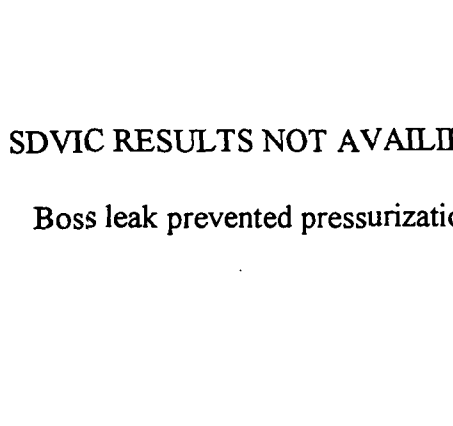
SDVIC RESULTS NOT AVAILIBLE.

Boss leak prevented pressurization.

A.3. VICNET NEURAL NETWORK INTERFACE

A.3.1. VICNET ABOUT BOX
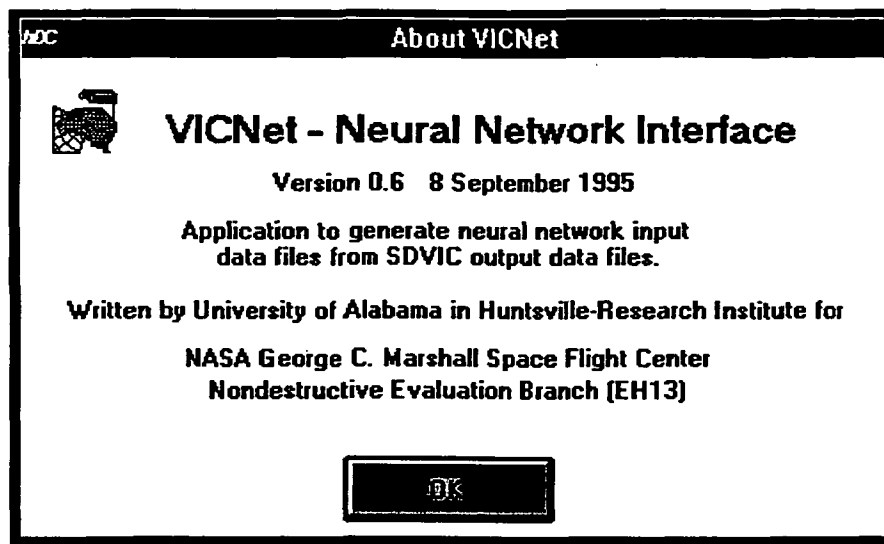
File: A_VICNET.FRM

```
VERSION 2.00                                    Height     = 480
Begin Form Frm_AbtVICNet                        Left       = 240
  BorderStyle  = 3 'Fixed Double                Picture    = A_VICNET.FRX:0000
  Caption      = "About VICNet"                 ScaleHeight = 480
  ClientHeight = 3630                           ScaleWidth  = 480
  ClientLeft   = 4275                           TabIndex   = 0
  ClientTop    = 2595                           Top        = 240
  ClientWidth  = 6480                           Width      = 480
  Height       = 4035                         End
  Left         = 4215                         Begin Label Label6
  LinkTopic    = "Form1"                        Alignment   = 2 'Center
  MaxButton    = 0 'False                       Caption     = "Nondestructive Evaluation
  MinButton    = 0 'False                     Branch (EH13)"
  ScaleHeight  = 3630                           Height     = 255
  ScaleWidth   = 6480                           Left       = 0
  Top          = 2250                           TabIndex   = 7
  Width        = 6600                           Top        = 2400
  Begin CommandButton Command1                  Width      = 6375
    Caption    = "OK"                         End
    Default    = -1 'True                     Begin Label Label5
    Height     = 495                            Alignment   = 2 'Center
    Left       = 2400                           Caption     = "NASA George C.
    TabIndex   = 4                           Marshall Space Flight Center"
    Top        = 3000                           Height     = 255
    Width      = 1575                           Left       = 0
  End                                           TabIndex   = 6
Begin PictureBox Picture1                        Top        = 2160
    AutoSize   = -1 'True                        Width      = 6375
    BorderStyle = 0 'None                      End
```

```
Begin Label Label4                          Top        = 840
    Alignment    = 2 'Center                Width      = 6255
    Caption      = "Written by University of End
Alabama in Huntsville-Research Institute for"  Begin Label Label1
    Height    = 255                             Caption     = "VICNet - Neural Network
    Left      = 120                         Interface"
    TabIndex  = 5                               FontBold     = -1 'True
    Top       = 1800                            FontItalic   = 0  'False
    Width     = 6255                            FontName     = "MS Sans Serif"
End                                             FontSize     = 13.5
Begin Label Label3                              FontStrikethru = 0 'False
    Alignment    = 2 'Center                    FontUnderline  = 0 'False
    Caption      = "Application to generate     Height     = 375
neural network input data files from SDVIC      Left       = 1080
output data files."                             TabIndex   = 1
    Height    = 495                             Top        = 360
    Left      = 1200                            Width      = 5295
    TabIndex  = 3                           End
    Top       = 1200                        End
    Width     = 3855
End                                         Sub Command1_Click ()
Begin Label Label2
    Alignment    = 2 'Center                Frm_AbtVICNet.Visible = False
    Caption      = "Version 0.6   8 September  Frm_VICNet.Visible = True
1995"                                       Frm_VICNet.SetFocus
    Height    = 255
    Left      = 120                         End Sub
    TabIndex  = 2
```

A.3.2. VICNET MAIN WINDOW

```
╔═══════════════════════════════════════════════════════════════════════════╗
║ hOC              VICNet 0.6 - Neural Net Interface               [–][□]     ║
╠═══════════════════════════════════════════════════════════════════════════╣
```

			YIN	YAX	PTS
	3000	c:\vic\summer95\unfilled\d201\d2012161.dat	-7	20	17956
	3000	c:\vic\summer95\unfilled\d233\d2332041.dat	-4	15	17956
	2608	c:\vic\summer95\unfilled\d169\d1692043.dat	-14	23	17956
	2407	c:\vic\summer95\unfilled\d187\d1872043.dat	-10	29	17956
	2354	c:\vic\summer95\unfilled\d241\d2412043.dat	-7	19	17956
	2237	c:\vic\summer95\unfilled\d177\d1772045.dat	-12	27	11211
	2149	c:\vic\summer95\unfilled\d225\d2252041.dat	-10	27	17956
	1701	c:\vic\summer95\unfilled\d235\d2352042.dat	-36	41	17956
	1541	c:\vic\summer95\unfilled\d254\d2542043.dat	-14	29	17956

k-empty.nna   18   -4   15   1.05

Settings Restored. READY.

File: VICNET.FRM

VERSION 2.00
Begin Form Frm_VICNet
  BackColor   =   &H00C0C0C0&
  Caption   =   "VICNet 0.6 - Neural Net Interface"
  ClientHeight =   4665
  ClientLeft   =   2670
  ClientTop   =   2130
  ClientWidth =   9690
  Height   =   5355
  Icon   =   VICNET.FRX:0000
  Left   =   2610
  LinkTopic   =   "Form1"
  ScaleHeight =   4665
  ScaleWidth   =   9690
  Top   =   1500
  Width   =   9810
  Begin TextBox Txt_Min
    Alignment   =   2 'Center
    Height   =   285
    Left   =   7440
    TabIndex   =   10
    Top   =   3960
    Width   =   615
  End
  Begin TextBox Txt_Burst
    Height   =   285
    Index   =   14
    Left   =   480
    TabIndex   =   39
    Top   =   3600
    Width   =   855
  End
  Begin TextBox Txt_Burst
    Height   =   285
    Index   =   13
    Left   =   480
    TabIndex   =   37
    Top   =   3360
    Width   =   855
  End
  Begin TextBox Txt_Burst
    Height   =   285
    Index   =   12
    Left   =   480
    TabIndex   =   35
    Top   =   3120
    Width   =   855
  End
  Begin TextBox Txt_Burst
    Height   =   285
    Index   =   11
    Left   =   480
    TabIndex   =   33
    Top   =   2880
    Width   =   855
  End
  Begin TextBox Txt_Burst
    Height   =   285
    Index   =   10
    Left   =   480
    TabIndex   =   31
```

```
      Top        =  2640                  Left       =  480
      Width      =  855                   TabIndex     =  17
End                                       Top        =  1200
Begin TextBox Txt_Burst                   Width      =  855
   Height      =  285                  End
   Index       =  9                    Begin TextBox Txt_Burst
   Left        =  480                     Height     =  285
   TabIndex      =  29                     Index      =  3
   Top         =  2400                     Left       =  480
   Width       =  855                      TabIndex     =  16
End                                        Top        =  960
Begin TextBox Txt_Burst                    Width      =  855
   Height      =  285                  End
   Index       =  8                    Begin TextBox Txt_Burst
   Left        =  480                     Height     =  285
   TabIndex      =  27                     Index      =  2
   Top         =  2160                     Left       =  480
   Width       =  855                      TabIndex     =  15
End                                        Top        =  720
Begin TextBox Txt_Burst                    Width      =  855
   Height      =  285                  End
   Index       =  7                    Begin TextBox Txt_Burst
   Left        =  480                     Height     =  285
   TabIndex      =  25                     Index      =  1
   Top         =  1920                     Left       =  480
   Width       =  855                      TabIndex     =  14
End                                        Top        =  480
Begin TextBox Txt_Burst                    Width      =  855
   Height      =  285                  End
   Index       =  6                    Begin TextBox Txt_Burst
   Left        =  480                     Height     =  285
   TabIndex      =  23                     Index      =  0
   Top         =  1680                     Left       =  480
   Width       =  855                      TabIndex     =  13
End                                        Top        =  240
Begin TextBox Txt_Burst                    Width      =  855
   Height      =  285                  End
   Index       =  5                    Begin TextBox Txt_Num
   Left        =  480                     Alignment    =  2 'Center
   TabIndex      =  21                     Height     =  285
   Top         =  1440                     Left       =  5280
   Width       =  855                      TabIndex     =  12
End                                        Text       =  "41"
Begin TextBox Txt_NetFile                  Top        =  3960
   Height      =  285                      Width      =  855
   Left        =  1440                 End
   TabIndex      =  19                  Begin TextBox Txt_Max
   Text        =  "vicnet.nna"            Alignment    =  2 'Center
   Top         =  3960                     Height     =  285
   Width       =  1335                     Left       =  8160
End                                        TabIndex     =  11
Begin TextBox Txt_Burst                    Top        =  3960
   Height      =  285                      Width      =  615
   Index       =  4                    End
```

```
Begin Label Lbl_Dval
   Alignment      =  2  'Center
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Left        =  8880
   TabIndex       =  102
   Top         =  3960
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  14
   Left        =  8880
   TabIndex       =  101
   Top         =  3600
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  13
   Left        =  8880
   TabIndex       =  100
   Top         =  3360
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  12
   Left        =  8880
   TabIndex       =  99
   Top         =  3120
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  11
   Left        =  8880
   TabIndex       =  98
   Top         =  2880
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  10

   Left        =  8880
   TabIndex       =  97
   Top         =  2640
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  9
   Left        =  8880
   TabIndex       =  96
   Top         =  2400
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  8
   Left        =  8880
   TabIndex       =  95
   Top         =  2160
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  7
   Left        =  8880
   TabIndex       =  94
   Top         =  1920
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  6
   Left        =  8880
   TabIndex       =  93
   Top         =  1680
   Width       =  735
End
Begin Label Lbl_DatPts
   Alignment      =  1  'Right Justify
   BorderStyle    =  1  'Fixed Single
   Height      =  255
   Index       =  5
   Left        =  8880
   TabIndex       =  92
   Top         =  1440
   Width       =  735
```

```
End
Begin Label Lbl_DatPts
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  4
   Left         =  8880
   TabIndex     =  91
   Top          =  1200
   Width        =  735
End
Begin Label Lbl_DatPts
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  3
   Left         =  8880
   TabIndex     =  90
   Top          =  960
   Width        =  735
End
Begin Label Lbl_DatPts
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  2
   Left         =  8880
   TabIndex     =  89
   Top          =  720
   Width        =  735
End
Begin Label Lbl_DatPts
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  1
   Left         =  8880
   TabIndex     =  88
   Top          =  480
   Width        =  735
End
Begin Label Label4
   Alignment    =  2 'Center
   AutoSize     =  -1 'True
   BackColor    =  &H00C0C0C0&
   Caption      =  "PTS"
   Height       =  195
   Left         =  8880
   TabIndex     =  87
   Top          =  0
   Width        =  735
End
Begin Label Lbl_DatPts
   Alignment    =  1 'Right Justify
```

```
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  0
   Left         =  8880
   TabIndex     =  86
   Top          =  240
   Width        =  735
End
Begin Label Lbl_Max
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  14
   Left         =  8160
   TabIndex     =  85
   Top          =  3600
   Width        =  615
End
Begin Label Lbl_Min
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  14
   Left         =  7440
   TabIndex     =  84
   Top          =  3600
   Width        =  615
End
Begin Label Lbl_Max
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  13
   Left         =  8160
   TabIndex     =  83
   Top          =  3360
   Width        =  615
End
Begin Label Lbl_Min
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  13
   Left         =  7440
   TabIndex     =  82
   Top          =  3360
   Width        =  615
End
Begin Label Lbl_Max
   Alignment    =  1 'Right Justify
   BorderStyle  =  1 'Fixed Single
   Height       =  255
   Index        =  12
   Left         =  8160
```

```
    TabIndex     =  81
    Top          =  3120
    Width        =  615
End
Begin Label Lbl_Min
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  12
    Left         =  7440
    TabIndex     =  80
    Top          =  3120
    Width        =  615
End
Begin Label Lbl_Max
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  11
    Left         =  8160
    TabIndex     =  79
    Top          =  2880
    Width        =  615
End
Begin Label Lbl_Min
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  11
    Left         =  7440
    TabIndex     =  78
    Top          =  2880
    Width        =  615
End
Begin Label Lbl_Max
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  10
    Left         =  8160
    TabIndex     =  77
    Top          =  2640
    Width        =  615
End
Begin Label Lbl_Min
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  10
    Left         =  7440
    TabIndex     =  76
    Top          =  2640
    Width        =  615
End
```

```
Begin Label Lbl_Max
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  9
    Left         =  8160
    TabIndex     =  75
    Top          =  2400
    Width        =  615
End
Begin Label Lbl_Min
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  9
    Left         =  7440
    TabIndex     =  74
    Top          =  2400
    Width        =  615
End
Begin Label Lbl_Max
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  8
    Left         =  8160
    TabIndex     =  73
    Top          =  2160
    Width        =  615
End
Begin Label Lbl_Min
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  8
    Left         =  7440
    TabIndex     =  72
    Top          =  2160
    Width        =  615
End
Begin Label Lbl_Max
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
    Index        =  7
    Left         =  8160
    TabIndex     =  71
    Top          =  1920
    Width        =  615
End
Begin Label Lbl_Min
    Alignment    =  1  'Right Justify
    BorderStyle  =  1  'Fixed Single
    Height       =  255
```

```
     Index       = 7
     Left        = 7440
     TabIndex    = 70
     Top         = 1920
     Width       = 615
  End
  Begin Label Lbl_Max
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 6
     Left        = 8160
     TabIndex      = 69
     Top         = 1680
     Width       = 615
  End
  Begin Label Lbl_Min
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 6
     Left        = 7440
     TabIndex      = 68
     Top         = 1680
     Width       = 615
  End
  Begin Label Lbl_Max
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 5
     Left        = 8160
     TabIndex      = 67
     Top         = 1440
     Width       = 615
  End
  Begin Label Lbl_Min
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 5
     Left        = 7440
     TabIndex      = 66
     Top         = 1440
     Width       = 615
  End
  Begin Label Lbl_Max
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 4
     Left        = 8160
     TabIndex      = 65
     Top         = 1200
```

```
     Width       = 615
  End
  Begin Label Lbl_Min
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 4
     Left        = 7440
     TabIndex      = 64
     Top         = 1200
     Width       = 615
  End
  Begin Label Lbl_Max
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 3
     Left        = 8160
     TabIndex      = 63
     Top         = 960
     Width       = 615
  End
  Begin Label Lbl_Min
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 3
     Left        = 7440
     TabIndex      = 62
     Top         = 960
     Width       = 615
  End
  Begin Label Lbl_Max
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 2
     Left        = 8160
     TabIndex      = 61
     Top         = 720
     Width       = 615
  End
  Begin Label Lbl_Min
     Alignment     = 1  'Right Justify
     BorderStyle   = 1  'Fixed Single
     Height        = 255
     Index       = 2
     Left        = 7440
     TabIndex      = 60
     Top         = 720
     Width       = 615
  End
  Begin Label Lbl_Max
     Alignment     = 1  'Right Justify
```

```
  BorderStyle  =  1  'Fixed Single          Caption    =  "14"
  Height      =  255                        Height     =  255
  Index       =  1                          Index      =  13
  Left        =  8160                       Left       =  120
  TabIndex    =  59                         TabIndex   =  43
  Top         =  480                        Top        =  3360
  Width       =  615                        Width      =  255
End                                      End
Begin Label Lbl_Min                      Begin Label Label2
  Alignment   =  1  'Right Justify          Alignment  =  2  'Center
  BorderStyle =  1  'Fixed Single          BackColor  =  &H00C0C0C0&
  Height      =  255                        BorderStyle =  1  'Fixed Single
  Index       =  1                          Caption    =  "13"
  Left        =  7440                       Height     =  255
  TabIndex    =  58                         Index      =  12
  Top         =  480                        Left       =  120
  Width       =  615                        TabIndex   =  44
End                                        Top        =  3120
Begin Label Lbl_Max                        Width      =  255
  Alignment   =  1  'Right Justify        End
  BorderStyle =  1  'Fixed Single        Begin Label Label2
  Height      =  255                        Alignment  =  2  'Center
  Index       =  0                          BackColor  =  &H00C0C0C0&
  Left        =  8160                       BorderStyle =  1  'Fixed Single
  TabIndex    =  57                         Caption    =  "12"
  Top         =  240                        Height     =  255
  Width       =  615                        Index      =  11
End                                        Left       =  120
Begin Label Lbl_Min                        TabIndex   =  45
  Alignment   =  1  'Right Justify          Top        =  2880
  BorderStyle =  1  'Fixed Single          Width      =  255
  Height      =  255                      End
  Index       =  0                        Begin Label Label2
  Left        =  7440                       Alignment  =  2  'Center
  TabIndex    =  56                         BackColor  =  &H00C0C0C0&
  Top         =  240                        BorderStyle =  1  'Fixed Single
  Width       =  615                        Caption    =  "11"
End                                        Height     =  255
Begin Label Label2                         Index      =  10
  Alignment   =  2  'Center                 Left       =  120
  BackColor   =  &H00C0C0C0&                TabIndex   =  46
  BorderStyle =  1  'Fixed Single          Top        =  2640
  Caption     =  "15"                       Width      =  255
  Height      =  255                      End
  Index       =  14                       Begin Label Label2
  Left        =  120                         Alignment  =  2  'Center
  TabIndex    =  42                         BackColor  =  &H00C0C0C0&
  Top         =  3600                       BorderStyle =  1  'Fixed Single
  Width       =  255                        Caption    =  "10"
End                                        Height     =  255
Begin Label Label2                         Index      =  9
  Alignment   =  2  'Center                 Left       =  120
  BackColor   =  &H00C0C0C0&                TabIndex   =  47
  BorderStyle =  1  'Fixed Single          Top        =  2400
```

```
    Width       =  255                      Caption      =  "5"
End                                         Height       =  255
Begin Label Label2                          Index        =  4
   Alignment    =  2 'Center                Left         =  120
   BackColor    =  &H00C0C0C0&              TabIndex     =  52
   BorderStyle  =  1 'Fixed Single          Top          =  1200
   Caption      =  "9"                      Width        =  255
   Height       =  255                   End
   Index        =  8                     Begin Label Label2
   Left         =  120                      Alignment    =  2 'Center
   TabIndex     =  48                       BackColor    =  &H00C0C0C0&
   Top          =  2160                     BorderStyle  =  1 'Fixed Single
   Width        =  255                      Caption      =  "4"
End                                         Height       =  255
Begin Label Label2                          Index        =  3
   Alignment    =  2 'Center                Left         =  120
   BackColor    =  &H00C0C0C0&              TabIndex     =  51
   BorderStyle  =  1 'Fixed Single          Top          =  960
   Caption      =  "8"                      Width        =  255
   Height       =  255                   End
   Index        =  7                     Begin Label Label2
   Left         =  120                      Alignment    =  2 'Center
   TabIndex     =  55                       BackColor    =  &H00C0C0C0&
   Top          =  1920                     BorderStyle  =  1 'Fixed Single
   Width        =  255                      Caption      =  "3"
End                                         Height       =  255
Begin Label Label2                          Index        =  2
   Alignment    =  2 'Center                Left         =  120
   BackColor    =  &H00C0C0C0&              TabIndex     =  50
   BorderStyle  =  1 'Fixed Single          Top          =  720
   Caption      =  "7"                      Width        =  255
   Height       =  255                   End
   Index        =  6                     Begin Label Label2
   Left         =  120                      Alignment    =  2 'Center
   TabIndex     =  54                       BackColor    =  &H00C0C0C0&
   Top          =  1680                     BorderStyle  =  1 'Fixed Single
   Width        =  255                      Caption      =  "2"
End                                         Height       =  255
Begin Label Label2                          Index        =  1
   Alignment    =  2 'Center                Left         =  120
   BackColor    =  &H00C0C0C0&              TabIndex     =  49
   BorderStyle  =  1 'Fixed Single          Top          =  480
   Caption      =  "6"                      Width        =  255
   Height       =  255                   End
   Index        =  5                     Begin Label Label2
   Left         =  120                      Alignment    =  2 'Center
   TabIndex     =  53                       BackColor    =  &H00C0C0C0&
   Top          =  1440                     BorderStyle  =  1 'Fixed Single
   Width        =  255                      Caption      =  "1"
End                                         ForeColor    =  &H00000000&
Begin Label Label2                          Height       =  255
   Alignment    =  2 'Center                Index        =  0
   BackColor    =  &H00C0C0C0&              Left         =  120
   BorderStyle  =  1 'Fixed Single          TabIndex     =  41
```

```
    Top        =  240                        Top        =  2400
    Width      =  255                        Width      =  5895
End                                      End
Begin Label Lbl_DatFile                  Begin Label Lbl_DatFile
  BorderStyle  =  1 'Fixed Single          BorderStyle  =  1 'Fixed Single
  Height       =  255                       Height       =  255
  Index        =  14                        Index        =  8
  Left         =  1440                      Left         =  1440
  TabIndex     =  40                        TabIndex     =  28
  Top          =  3600                      Top          =  2160
  Width        =  5895                      Width        =  5895
End                                      End
Begin Label Lbl_DatFile                  Begin Label Lbl_DatFile
  BorderStyle  =  1 'Fixed Single          BorderStyle  =  1 'Fixed Single
  Height       =  255                       Height       =  255
  Index        =  13                        Index        =  7
  Left         =  1440                      Left         =  1440
  TabIndex     =  38                        TabIndex     =  26
  Top          =  3360                      Top          =  1920
  Width        =  5895                      Width        =  5895
End                                      End
Begin Label Lbl_DatFile                  Begin Label Lbl_DatFile
  BorderStyle  =  1 'Fixed Single          BorderStyle  =  1 'Fixed Single
  Height       =  255                       Height       =  255
  Index        =  12                        Index        =  6
  Left         =  1440                      Left         =  1440
  TabIndex     =  36                        TabIndex     =  24
  Top          =  3120                      Top          =  1680
  Width        =  5895                      Width        =  5895
End                                      End
Begin Label Lbl_DatFile                  Begin Label Lbl_DatFile
  BorderStyle  =  1 'Fixed Single          BorderStyle  =  1 'Fixed Single
  Height       =  255                       Height       =  255
  Index        =  11                        Index        =  5
  Left         =  1440                      Left         =  1440
  TabIndex     =  34                        TabIndex     =  22
  Top          =  2880                      Top          =  1440
  Width        =  5895                      Width        =  5895
End                                      End
Begin Label Lbl_DatFile                  Begin Label Lbl_Status
  BorderStyle  =  1 'Fixed Single          Alignment    =  2 'Center
  Height       =  255                       BackColor    =  &H00000000&
  Index        =  10                        Caption      =  "READY"
  Left         =  1440                      ForeColor    =  &H0000FF00&
  TabIndex     =  32                        Height       =  255
  Top          =  2640                      Left         =  120
  Width        =  5895                      TabIndex     =  20
End                                        Top          =  4320
Begin Label Lbl_DatFile                    Width        =  9495
  BorderStyle  =  1 'Fixed Single        End
  Height       =  255                    Begin Label Label8
  Index        =  9                        BackColor    =  &H00C0C0C0&
  Left         =  1440                     Caption      =  "NetFile Name:"
  TabIndex     =  30                       Height       =  255
```

```
      Left       =   120                  Begin Label Lbl_DatFile
      TabIndex   =   18                      BorderStyle  =  1  'Fixed Single
      Top        =   3960                    Height     =   255
      Width      =   1335                    Index      =   3
   End                                       Left       =   1440
   Begin Label Label7                        TabIndex   =   4
      BackColor    =   &H00C0C0C0&           Top        =   960
      Caption    =   "Number of Input        Width      =   5895
Neurons:"                                 End
      Height     =   255                  Begin Label Lbl_DatFile
      Left       =   3000                    BorderStyle  =  1  'Fixed Single
      TabIndex   =   9                       Height     =   255
      Top        =   3960                    Index      =   2
      Width      =   2295                    Left       =   1440
   End                                       TabIndex   =   3
   Begin Label Label6                        Top        =   720
      Alignment    =   2  'Center            Width      =   5895
      BackColor    =   &H00C0C0C0&        End
      Caption    =   "MAX"                Begin Label Lbl_DatFile
      Height     =   255                     BorderStyle  =  1  'Fixed Single
      Left       =   8160                     Height     =   255
      TabIndex   =   8                       Index      =   1
      Top        =   0                       Left       =   1440
      Width      =   615                     TabIndex   =   2
   End                                       Top        =   480
   Begin Label Label5                        Width      =   5895
      Alignment    =   2  'Center         End
      BackColor    =   &H00C0C0C0&        Begin Label Lbl_DatFile
      Caption    =   "MIN"                   BorderStyle  =  1  'Fixed Single
      Height     =   255                     Height     =   255
      Left       =   7440                    Index      =   0
      TabIndex   =   7                       Left       =   1440
      Top        =   0                       TabIndex   =   1
      Width      =   615                     Top        =   240
   End                                       Width      =   5895
   Begin Label Label3                     End
      Alignment    =   2  'Center         Begin Label Label1
      BackColor    =   &H00C0C0C0&           Alignment    =   2  'Center
      Caption    =   "Burst Pressures:"      BackColor    =   &H00C0C0C0&
      Height     =   255                     Caption    =   "SDVIC Files:"
      Left       =   0                       Height     =   255
      TabIndex   =   6                       Left       =   1440
      Top        =   0                       TabIndex   =   0
      Width      =   1455                    Top        =   0
   End                                       Width      =   5895
   Begin Label Lbl_DatFile                End
      BorderStyle  =  1  'Fixed Single    Begin Menu Mnu_File
      Height     =   255                     Caption    =   "&File"
      Index      =   4                       Begin Menu Mnu_FileAdd
      Left       =   1440                       Caption    =   "&Add"
      TabIndex   =   5                          Shortcut   =   {F1}
      Top        =   1200                    End
      Width      =   5895                    Begin Menu Mnu_FileDelete
   End                                          Caption    =   "&Delete"
```

```
        Shortcut    = {F2}                    Frm_FName.Visible = True
    End                                       Frm_FName.SetFocus
    Begin Menu Mnu_FileRange                  End Sub
        Caption   = "&Range"
        Shortcut    = {F5}                    Sub Mnu_FileBoth_Click ()
    End                                       Mnu_FileRange = True
    Begin Menu Mnu_FileNet                    Mnu_FileNet = True
        Caption   = "&Net"                    End Sub
        Shortcut    = {F6}
    End                                       Sub Mnu_FileDelete_Click ()
    Begin Menu Mnu_FileExit                       Flag% = Flag% - 1
        Caption   = "E&xit"                       Lbl_DatFile(Flag%).Caption = ""
        Shortcut    = {F7}                    End Sub
    End
End                                           Sub Mnu_FileExit_Click ()
Begin Menu Mnu_Settings                       Close
    Caption     = "&Settings"                 End
    Begin Menu Mnu_SetClear                   End Sub
        Caption   = "&Clear"
    End                                       Sub Mnu_FileNet_Click ()
    Begin Menu Mnu_SetSave                    Lbl_Status.Caption = "Generating Neural Net
        Caption   = "&Save"                   File..."
        Shortcut    = {F3}                    Lbl_Status.Refresh
    End                                       netfile$ = Txt_Netfile.Text
    Begin Menu Mnu_SetRestore                 Open "c:\vic\" + netfile$ For Output As #2
        Caption   = "&Restore"                'Count Files in List
        Shortcut    = {F4}                    For i% = 0 To 14
    End                                           If Len(Lbl_DatFile(i%).Caption) > 4 Then
End                                           NumFiles% = i% + 1
Begin Menu Mnu_Help                           Next i%
    Caption     = "&Help"                     'Read Interface Values
    Begin Menu Mnu_HelpAbout                  minval! = Val(Txt_Min.Text)
        Caption   = "&About VICNet"           numval% = Int(Val(Txt_Num.Text))
    End                                       dval! = (Val(Txt_Max.Text) -
  End                                         Val(Txt_Min.Text)) / numval%
End                                           If dval! < .5 Then
                                                  Mess$ = Str$(dval!) + " > 0.5"
Sub Btn_Select_Click (Index As Integer)           MsgBox Mess$, 0, "VICNet : Net"
                                              End If
Flag% = Index                                 'Step Through Data Files
                                              For i% = 0 To NumFiles% - 1
End Sub                                            burst% = Int(Val(Txt_Burst(i%).Text))
                                                  infile$ = Lbl_DatFile(i%).Caption
Sub Form_Load ()                                  numpts% = Val(Lbl_DatPts(i%).Caption)
Flag% = 0                                         Open infile$ For Input As #1
End Sub                                           Idiot$ = "(" + Str$(i% + 1) + "/" +
                                              Str$(NumFiles%) + ")"
Sub Lbl_DatFile_Click (Index As Integer)          Lbl_Status.Caption = "Analyzing SDVIC
    Flag% = Index                             Data File " + Idiot$
    Frm_FName.Visible = True                      Label2(i%).BackColor = &HFF0000
    Frm_FName.SetFocus                            Label2(i%).ForeColor = &HFFFFFF
End Sub                                            Frm_VICNet.Refresh
                                                  'Call  Analysis Routine
Sub Mnu_FileAdd_Click ()
```

```
      Actual burst%, numval%, minval!, dval!,
numpts%
    Close #1
    DoEvents
Next i%
Close #2
Beep
MsgBox "Neural Net Data File Complete.", 0,
"Message from VICNet"
For j% = 0 To 14
    Frm_VICNet.Label2(j%).BackColor =
&HC0C0C0
    Frm_VICNet.Label2(j%).ForeColor = &H0
Next j%
Lbl_Status.Caption = "READY"
End Sub


Sub Mnu_FileRange_Click ()
MinStrain! = 1000!
MaxStrain! = -1000!
For i% = 0 To 14
    If
Len(Frm_VICNet.Lbl_DatFile(i%).Caption) > 4
Then NumFiles% = i% + 1
Next i%
For j% = 0 To NumFiles% - 1
    infile$ =
Frm_VICNet.Lbl_DatFile(j%).Caption
    Open infile$ For Input As #1
    Idiot$ = "(" + Str$(j% + 1) + "/" +
Str$(NumFiles%) + ")"
    Frm_VICNet.Lbl_Status.Caption = "Ranging
SDVIC Data File " + Idiot$
    Frm_VICNet.Label2(j%).BackColor =
&HFF0000
    Frm_VICNet.Label2(j%).ForeColor =
&HFFFFFF
    Frm_VICNet.Refresh
    numpts% = 0
    TMin! = 1000!
    TMax! = -1000!
    Do
      buffer$ = Input$(66, #1)
      numpts% = numpts% + 1
      strain! = 1000 * Val(Mid$(buffer$, 58, 7))
      If Abs(strain!) > 1000 Then
        MsgBox "ERROR: |dv/dy=" +
Str$(strain!) + "|>1000", 0, "VICNet : Sub
Range"
      End If
      If strain! < TMin! Then
        TMin! = strain!
        Frm_VICNet.Lbl_Min(j%).Caption =
Str$(TMin!)
```

```
        Frm_VICNet.Lbl_Max(j%).Caption =
Str$(TMax!)
      End If
      If strain! > TMax! Then
        TMax! = strain!
        Frm_VICNet.Lbl_Min(j%).Caption =
Str$(TMin!)
        Frm_VICNet.Lbl_Max(j%).Caption =
Str$(TMax!)
      End If
      If TMin! < MinStrain! Then
        MinStrain! = TMin!
      End If
      If strain! > MaxStrain! Then
        MaxStrain! = TMax!
      End If
    Loop Until EOF(1)
    Close #1
    Txt_Min.Text = Str$(MinStrain!)
    Txt_Max.Text = Str$(MaxStrain!)
    Lbl_DatPts(j%).Caption = Str$(numpts%)
    Frm_VICNet.Refresh
    DoEvents
Next j%
Frm_VICNet.Txt_Min.Text = Str$(MinStrain!)
Frm_VICNet.Txt_Max.Text = Str$(MaxStrain!)
Beep
MsgBox "SDVIC Data Files Ranged.", 0,
"Message from VICNet"
For j% = 0 To 14
    Frm_VICNet.Label2(j%).BackColor =
&HC0C0C0
    Frm_VICNet.Label2(j%).ForeColor = &H0
Next j%
Frm_VICNet.Lbl_Status.Caption = "Ranging
Completed.  READY."
End Sub


Sub Mnu_HelpAbout_Click ()
Frm_AbtVICNet.Visible = True
Frm_AbtVICNet.SetFocus
End Sub


Sub Mnu_SetClear_Click ()
Lbl_Status.Caption = "Clearing Settings..."
For i% = 0 To 14
    Lbl_DatFile(i%).Caption = ""
    Txt_Burst(i%).Text = ""
    Lbl_Min(i%).Caption = ""
    Lbl_Max(i%).Caption = ""
Next i%
Txt_Netfile.Text = "*.nna"
Txt_Min.Text = ""
Txt_Max.Text = ""
```

```
Txt_Num.Text = ""                        Print #2, Txt_Min.Text
Flag% = 0                                Print #2, Txt_Max.Text
Lbl_Status.Caption = "Settings Cleared.  Print #2, Txt_Num.Text
READY."                                  Print #2, Txt_Netfile.Text
End Sub                                   Close
                                         Lbl_Status.Caption = "Settings Saved.
Sub Mnu_SetRestore_Click ()              READY."
Frm_SName.Visible = True                 End Sub
Frm_SName.SetFocus
End Sub                                   Sub Txt_Max_Change ()
                                         Lbl_Dval.Caption =
Sub Mnu_SetSave_Click ()                 Left$(Str$((Val(Txt_Max.Text) -
x$ = "x"                                 Val(Txt_Min.Text)) / Val(Txt_Num.Text)), 5)
setfile$ = Left$(Txt_Netfile.Text,       Lbl_Dval.Refresh
Len(Txt_Netfile.Text) - 3) + "set"       End Sub
Lbl_Status.Caption = "Saving Settings to " +
setfile$                                 Sub Txt_Min_Change ()
setfile$ = "c:\vic\" + setfile$          Lbl_Dval.Caption =
Open setfile$ For Output As #2           Left$(Str$((Val(Txt_Max.Text) -
For i% = 0 To 14                         Val(Txt_Min.Text)) / (Val(Txt_Num.Text))), 5)
   If Val(Txt_Burst(i%).Text) > 0 Then   Lbl_Dval.Refresh
      Print #2, Txt_Burst(i%).Text; ","; End Sub
Lbl_DatFile(i%).Caption; ",";
Lbl_Min(i%).Caption; ",";                Sub Txt_Num_Change ()
Lbl_Max(i%).Caption; ",";                Lbl_Dval.Caption =
Lbl_DatPts(i%).Caption                   Left$(Str$((Val(Txt_Max.Text) -
   Else                                  Val(Txt_Min.Text)) / Val(Txt_Num.Text)), 5)
      Print #2, x$; ","; x$; ","; x$; ","; x$; ","; x$   Lbl_Dval.Refresh
   End If                                End Sub
Next i%
```

A.3.3. SDVIC DATA FILE NAME REQUEST WINDOW

File: GETFNAME.FRM

(1-2)

```
VERSION 2.00
Begin Form Frm_FName
  BackColor    =  &H00E0E0E0&
  Caption      =  "Select File"
  ClientHeight =  3525
  ClientLeft   =  4515
  ClientTop    =  2820
  ClientWidth  =  6000
  Height       =  3930
  Icon         =  GETFNAME.FRX:0000
  Left         =  4455
  LinkTopic    =  "Form1"
  ScaleHeight  =  3525
  ScaleWidth   =  6000
  Top          =  2475
  Width        =  6120
  Begin CommandButton Btn_Cancel
    Caption    =  "Cancel"
    Height     =  375
    Left       =  3120
    TabIndex   =  5
    Top        =  3120
    Width      =  2775
  End
  Begin CommandButton Btn_OK
    Caption    =  "OK"
    Height     =  375
    Left       =  120
    TabIndex   =  4
    Top        =  3120
    Width      =  2775
  End
  Begin TextBox Txt_FName
    Height     =  285
    Left       =  3120
    TabIndex   =  3
    Text       =  "*.*"
    Top        =  360
    Width      =  2775
  End
  Begin FileListBox File1
    Height     =  1980
    Left       =  3120
    Pattern    =  "*.dat"
    TabIndex   =  2
    Top        =  960
    Width      =  2775
  End
  Begin DirListBox Dir1
    Height     =  1605
    Left       =  120
    TabIndex   =  1
    Top        =  1320
    Width      =  2775
  End
  Begin DriveListBox Drive1
    Height     =  315
    Left       =  120
    TabIndex   =  0
    Top        =  360
    Width      =  2775
  End
  Begin Label Lbl_CurrentDir
    BackColor  =  &H00FFFFFF&
    Caption    =  "c:\"
    Height     =  255
    Left       =  120
    TabIndex   =  9
    Top        =  960
    Width      =  2775
  End
  Begin Label Label4
    BackColor  =  &H00E0E0E0&
    Caption    =  "Drives:"
    Height     =  255
    Left       =  120
    TabIndex   =  8
    Top        =  120
    Width      =  1575
  End
  Begin Label Label3
    BackColor  =  &H00E0E0E0&
    Caption    =  "Directories:"
    Height     =  255
    Left       =  120
    TabIndex   =  7
    Top        =  720
    Width      =  1575
  End
  Begin Label Label2
    BackColor  =  &H00E0E0E0&
    Caption    =  "File Name:"
    Height     =  255
    Left       =  3120
    TabIndex   =  6
    Top        =  120
    Width      =  1575
  End
End
Sub Btn_Cancel_Click ()
  Frm_FName.Visible = False
  Frm_VICNet.SetFocus
End Sub
```

```
Sub Btn_OK_Click ()                              Sub File1_Click ()
   Frm_FName.Visible = False                        Txt_FName.Text = Dir1.List(-1) + "\" +
   Frm_VICNet.SetFocus                           File1.FileName
   Frm_VICNet.Lbl_DatFile(Flag%).Caption =       End Sub
Txt_FName.Text
   Flag% = Flag% + 1
End Sub                                          Sub File1_DblClick ()

Sub Dir1_Change ()                               Txt_FName.Text = Dir1.List(-1) + "\" +
   File1.Path = Dir1.List(-1)                     File1.FileName
   Txt_FName.Text = Dir1.List(-1) + "\*.dat"      Btn_OK = True
End Sub
                                                 End Sub
Sub Drive1_Change ()
                                                 Sub Form_Load ()
Dir1.Path = Drive1.Drive                            Dir1.Path = "c:\vic"
Txt_FName.Text = Dir1.List(-1) + "\*.dat"            Txt_FName.Text = Dir1.List(-1) + "\*.dat"
                                                 End Sub

End Sub
```

A.3.4. SETTINGS FILE NAME REQUEST WINDOW

File: SETFNAME.FRM

```
VERSION 2.00                                     Left       =  4440
Begin Form Frm_SName                             LinkTopic  =  "Form1"
   BackColor   =  &H00C0C0C0&                     ScaleHeight =  3615
   Caption     =  "Select File"                   ScaleWidth  =  6015
   ClientHeight =  3615                           Top        =  2475
   ClientLeft  =  4500                            Width      =  6135
   ClientTop   =  2820                            Begin CommandButton Btn_Cancel
   ClientWidth =  6015                               Caption    =  "Cancel"
   Height      =  4020                                Height     =  375
   Icon        =  SETFNAME.FRX:0000                  Left       =  4560
```

```
   TabIndex    = 5                          Height     = 255
   Top         = 120                        Left       = 120
   Width       = 1335                       TabIndex   = 9
End                                         Top        = 960
Begin CommandButton Btn_OK                  Width      = 2775
   Caption     = "OK"                    End
   Height      = 375                     Begin Label Label4
   Left        = 3120                       BackColor   = &H00C0C0C0&
   TabIndex    = 4                          Caption     = "Drives:"
   Top         = 120                        Height      = 255
   Width       = 1335                       Left        = 120
End                                         TabIndex    = 8
Begin TextBox Txt_FName                      Top         = 120
   Height      = 285                        Width       = 1575
   Left        = 120                     End
   TabIndex    = 3                       Begin Label Label3
   Text        = "*.*"                      BackColor   = &H00C0C0C0&
   Top         = 3240                       Caption     = "Directories:"
   Width       = 5775                       Height      = 255
End                                         Left        = 120
Begin FileListBox File1                      TabIndex    = 7
   Height      = 2175                       Top         = 720
   Left        = 3120                       Width       = 1575
   Pattern     = "*.set"                 End
   TabIndex    = 2                       Begin Label Label2
   Top         = 960                        BackColor   = &H00C0C0C0&
   Width       = 2775                       Caption     = "File Name:"
End                                         Height      = 255
Begin DirListBox Dir1                        Left        = 120
   Height      = 1605                       TabIndex    = 6
   Left        = 120                        Top         = 3000
   TabIndex    = 1                          Width       = 1575
   Top         = 1320                    End
   Width       = 2775                   End
End                                   End
Begin DriveListBox Drive1
   Height      = 315                   Sub Btn_Cancel_Click ()
   Left        = 120
   TabIndex    = 0                      Frm_SName.Visible = False
   Top         = 360                    Frm_VICNet.SetFocus
   Width       = 2775
End                                     End Sub
Begin Label Label1
   BackColor   = &H00C0C0C0&            Sub Btn_OK_Click ()
   Caption     = "Files:"               Frm_SName.Visible = False
   Height      = 255                    Frm_VICNet.SetFocus
   Left        = 3120                   Frm_VICNet.Lbl_Status.Caption = "Restoring
   TabIndex    = 10                     Settings from VICNET.SET"
   Top         = 600                    setfile$ = Txt_FName.Text
   Width       = 975                    x$ = ""
End                                     Open setfile$ For Input As #1
Begin Label Lbl_CurrentDir              For i% = 0 To 14
   BackColor   = &H00FFFFFF&               Input #1, buf1$, buf2$, buf3$, buf4$, buf5$
   Caption     = "c:\"                     If buf1$ <> "x" Then
                                              Frm_VICNet.Txt_Burst(i%).Text = buf1$
```

```
        Frm_VICNet.Lbl_DatFile(i%).Caption =
buf2$
        Frm_VICNet.Lbl_Min(i%).Caption =
buf3$
        Frm_VICNet.Lbl_Max(i%).Caption =
buf4$
        Frm_VICNet.Lbl_DatPts(i%).Caption =
buf5$
    Else
        Frm_VICNet.Txt_Burst(i%).Text = x$
        Frm_VICNet.Lbl_DatFile(i%).Caption =
x$
        Frm_VICNet.Lbl_Min(i%).Caption = x$
        Frm_VICNet.Lbl_Max(i%).Caption = x$
        Frm_VICNet.Lbl_DatPts(i%).Caption = x$
    End If
Next i%
Input #1, buf1$
Frm_VICNet.Txt_Min.Text = buf1$
Input #1, buf2$
Frm_VICNet.Txt_Max.Text = buf2$
Input #1, buf3$
Frm_VICNet.Txt_Num.Text = buf3$
Input #1, buf4$
Frm_VICNet.Txt_NetFile.Text = buf4$
Close
Frm_VICNet.Lbl_Dval.Caption =
Left$(Str$((Val(Frm_VICNet.Txt_Max.Text) -
Val(Frm_VICNet.Txt_Min.Text)) /
(Val(Frm_VICNet.Txt_Num.Text))), 5)
Frm_VICNet.Lbl_Status.Caption = "Settings
Restored.  READY."
End Sub
```

A.3.5. FORM INDEPENDENT CODE

File: VICNET.BAS

```
Global Flag%
Global temp!(10), LUT!(64)
Dim count%()

Sub Actual (burst%, numval%,minval!,
dval!,numpts%)
'Calculates histogram based upon actual dv/dy
values from SDVIC.
'Initialize variable values
ReDim count%(numval% + 1)
For i% = 0 To numval%
    count%(i%) = 0
Next i%
'Read each line, 64 char + CR + LF per line,
until end of file.
```

```
Sub Dir1_Change ()

File1.Path = Dir1.List(-1)
Txt_FName.Text = Dir1.List(-1) + "\*.dat"

End Sub

Sub Drive1_Change ()

Dir1.Path = Drive1.Drive
Txt_FName.Text = Dir1.List(-1) + "\*.dat"

End Sub

Sub File1_Click ()
Txt_FName.Text = Dir1.List(-1) + "\" +
File1.FileName
End Sub

Sub File1_DblClick ()

Txt_FName.Text = Dir1.List(-1) + "\" +
File1.FileName
Btn_OK = True

End Sub

Sub Form_Load ()
Dir1.Path = "c:\vic\"
Txt_FName.Text = Dir1.List(-1) + "\*.set"
End Sub
```

```
Do
    buffer$ = Input$(66, #1)
    dvdy! = 1000! * Val(Mid$(buffer$, 58, 7))
    'Trap for misread end of lines.
    If Abs(dvdy!) > 1000! Then
        MsgBox "ERROR: |dv/dy=" + Str$(dvdy!)
+ "|>1000", 0, "VICNet : Sub Actual"
    End If
    'Determine which of the numval% histogram
bars the current dv/dy is in.
    index% = Int(((dvdy! + (dval! / 2!)) -
minval!) / dval!)
    If ((index% > 0) And (index% < (numval% +
1))) Then count%(index%) = count%(index%) +
1
```

```
Loop Until EOF(1)
DoEvents
'Output Neural Net File (netfile.nna)
total% = 0
For i% = 1 To numval%
    If count%(i%) < 0 Then          'Trap for
negative count.
        Mess$ = "Count Less Than Zero (" +
Str$(count%(i%)) + ")."
        MsgBox Mess$, 0, "VICNet : Sub Actual"
        count%(i%) = 0
    End If
        total% = total% + count%(i%)
        Print #2, count%(i%); " ";
    Next i%
    If total% <> numpts% Then
        Mess$ = Str$(total%) + " / " +
Str$(numpts%) + " Points Counted."
        MsgBox Mess$, 0, "VICNet : Sub Actual"
    End If
    Print #2, burst%
End Sub
```

NASA

National Aeronautical and Space Agency

Report Document Page

1. Report No. 5-33567	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle

" Methods of Video and Shearography Inspection"

5. Report Due

September 1995

6. Performing Organization Code

Research Institute, UAH

7. Author(s)

Matthew D. Lansing, Michael W. Bullock,
William J. Gnacek

8. Performing Organization Report No.

5-33567

10. Work Unit No.

Delivery Order #119

9. Performing Organization Name and Address
UAH Research Institute
RI E-47
University of Alabama in Huntsville
Huntsville, AL 35899

11. Contract or Grant No.

NAS8-38609

13. Type of report and Period covered
Final Report
22 September 1994 through 21 September 1995

12. Sponsoring Agency Name and Address

National Aeronautics and Space Administration
Marshall Space Flight Center
Huntsville, AL 35812

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The goal of this research effort was to study methods of video image correlation and electronic shearography for nondestructive evaluation of aerospace components. Methods of physical load application must be developed before interrogations with these methods may be used to qualify hardware. To that end, inspection procedures were developed for a variety of aerospace components and material systems. Experiments were also conducted from which the relationship between the control settings of the electronic shearography apparatus may be related to flaw delectability. A short feasibility study was conducted to determine the applicability of electronic shearography to the determination of the stress intensity factor of a Mode I crack tip by measurement of the localized zone of three dimensional plasticity

17. Key Words (Suggested by Author(s))

experimental mechanics, flaw detection, fracture
video image correlation, NDE, nondestructive testing,
NDT, nondestructive evaluation, POD, probability of
detection, shearography

18. Distribution Statement

TBA

19. Security Class. (of this report) Unclassified	20. Security Class. (of this page) Unclassified	21. No. of pages 101	22. Price

NASA FORM 1626 OCT 86