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Standardized Methods for Electronic Shearography

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16. Abstract

The Systems Management and Production Laboratory at the University of Alabama in Huntsville (UAH) Research Institute was tasked by the Nondestructive Evaluation and Tribology Branch (EH13) at the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) to conduct research in development of operating procedures and standard methods to evaluate fiber reinforced composite materials, bonded or sprayed insulation, coatings, and laminated structures with MSFC electronic shearography systems. Optimal operating procedures were developed for the Pratt & Whitney Electronic Holography/Shearography Inspection System (EH/SIS) operating in shearography mode, as well as the Laser Technology, Inc. (LTI) SC-4000 and Ettemeyer SHS-94 ISTRA shearography systems. Operating practices for exciting the components being inspected were studied, including optimal methods for transient heating with heat lamps and other methods as appropriate to enhance inspection capability.

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I. INTRODUCTION

The Systems Management and Production Laboratory at the University of Alabama in Huntsville (UAH) Research Institute was tasked by the NDE and Tribology Branch (EH13) at the National Aeronautics and Space Administration (NASA) Marshall Space Flight Center (MSFC) to conduct research in development of operating procedures and standard methods to evaluate fiber reinforced composite materials, bonded or sprayed insulation, coatings, and laminated structures with MSFC electronic shearography systems. Optimal operating procedures were developed for the Pratt & Whitney Electronic Holography/Shearography Inspection System (EH/SIS) operating in shearography mode, as well as the Laser Technology Inc. (LTI) SC-4000 and Ettemeyer SHS-94 Istra shearography systems. Operating practices for exciting the components being inspected were studied, including optimal methods for transient heating with heat lamps and other methods as appropriate to enhance inspection capability.

II. SSME ALTERNATE TURBOPUMP HOUSING INSULATION

A. REPRESENTATIVE COUPONS

A study was conducted to assess the feasibility and performance limitations of shearography inspection for detection of unbonds in the Kevlar Filled Urethane Insulation (KFUI) on space shuttle main engine (SSME) turbopump housings. This study initially utilized flat coupons containing programmed defects to simulate the insulation package. Inspection methods were developed which result in detectability of all but the smallest flaws in all of the available specimens. In particular, inspection of flaws in the first three layers of roving before application of KFUI and outer roving provides detectability of all featured flaw sizes. The procedures and results of the study were documented and potential future actions for development of a certifiable inspection procedure for the SSME turbopump housing insulation package (THIP) were suggested.

1. Specimen

Circular inserts formed from two plies of Teflon with sealed edges simulated unbond inspection response in the coupons manufactured by DuPont. These inserts had sizes of 1.0, 1.9, 2.5, and 4.4 cm (3/8, 3/4, 1, and 1 3/4 inch). Table 1 details the structure of each specimen and Figure 1 illustrates insert positioning. The surface of all specimens were initially glossy, resulting in unwanted glare which obscures shearography detections. The specimens' surfaces were dulled using ScotchBrite pads supplied by DuPont, resulting in an acceptable finish for shearography.

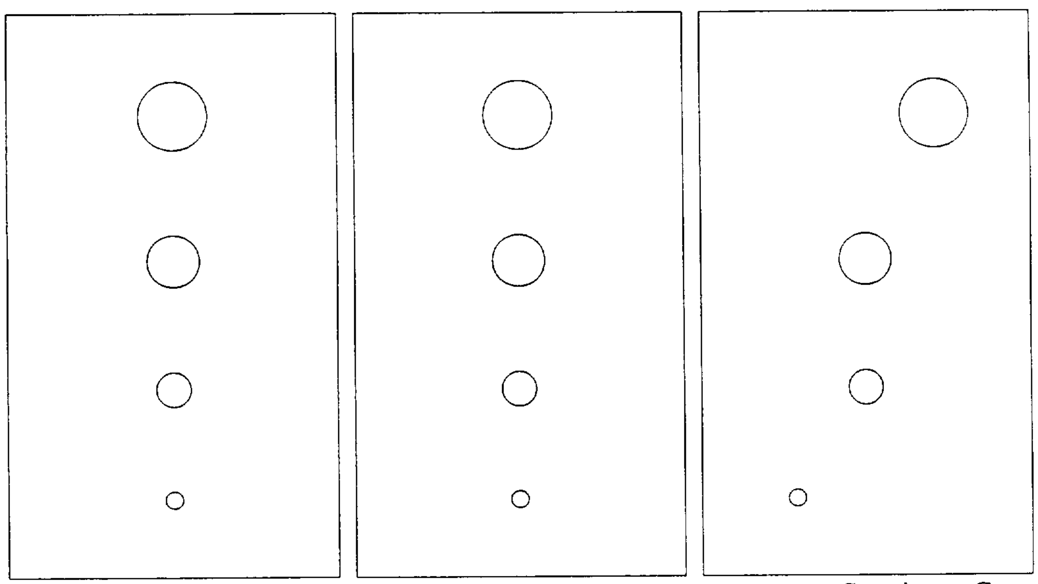
2. Vacuum Excitation

The UAH Research Institute Systems Management and Production Laboratory developed a vacuum chamber for shearography inspection for Marshall Space Flight Center under a previous contract delivery order. The vacuum chamber is constructed of

2.5 cm (1.0 inch) thick acrylic as shown in Figure 2. An industrial shop vacuum is used to reduce chamber pressure by approximately 21 kPa (3 psi).

Table 1. Specimen Structure

SPECIMEN	LAYERS	INSERT DEPTH
A	3 mm (1/8 inch) Inconel Plate 3 Layers of Inner Roving	Between 2nd and 3rd Layer of Inner Roving
B	Same as A plus 13 mm (1/2 inch) Cast KFUI	Between 3rd Layer of Roving and Cast KFUI
C	Same as B plus 3 Layers of Outer Roving	Between 2nd and 3rd Layer of Outer Roving
D	Same as C	No Inserts



Specimen A Specimen B Specimen C

Figure 1. Unbond Simulation Insert Positioning

The test coupons were placed in the vacuum chamber two at a time. Specimens A and C were inspected together, as were specimens B and D. A wooden box was used to prop the coupons up with only a slight tilt of the top away from the camera. The Pratt & Whitney Electronic Holography/Shearography Inspection System (EH/SIS) optical head was placed approximately 2 meters (6 feet) from the test article. The telephoto lens zoom and focus was adjusted with ambient lighting to fit the object distance and desired field of view. The ambient lighting was then turned off and the laser aperture was opened. The beam expander lens spacing was adjusted to maximize the illumination intensity and uniformity at the coupon surface. The camera F-stop was adjusted to suit this illumination. Image shear measured at the coupon surface was adjusted to 0.5 cm (0.2 inch) for specimens A and C and to 2.3 cm (0.9 inch) for specimens B and D. Increased image shear, and resultant sensitivity, was required for specimen B because of the increased flaw depth.

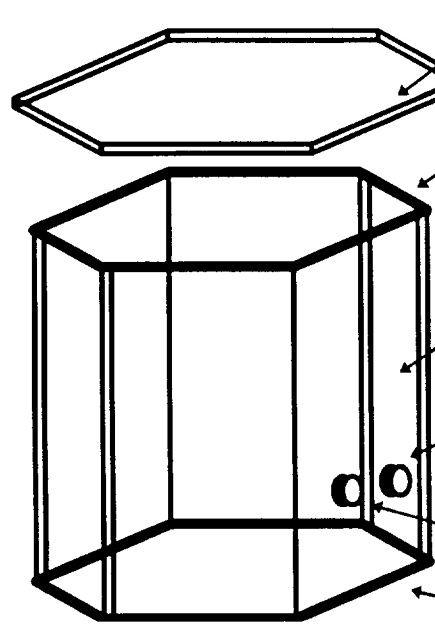


Figure 2. Schematic of Vacuum Chamber

With the chamber lid in place, the vent valve shut, and the draw valve open, the vacuum was turned on and allowed to run until chamber vacuum was approximately 21 kPa (3 psi). At that time, the draw valve was shut and the vacuum was turned off. After the vacuum motor had ceased spinning, a reference image was acquired. Minor leaks around the rubber gaskets caused the chamber vacuum pressure to drop, slowly returning to ambient pressure. This change in pressure provided sufficient excitation for flaw detection. As the chamber vacuum dropped from approximately 21 kPa (3 psi) to 17 kPa (2 psi) the surface deformation revealed the inserts in the shearography interference pattern as shown in Figure 3. The subtracted image was acquired within this pressure interval when the flaws became evident and the pattern became stable. At lesser vacuums, the leak rate was sufficiently slow and the defect deformation was sufficiently small that the inserts were no longer detectable.

It was discovered that better results were obtained when the chamber and specimen had spent a number of hours at ambient pressure than if the pressure had been recently cycled. It is suspected that the open edges allowed air to seep in and out of voids in the material over time. Application of vacuum drew this air out, causing deformation of the insulation which accentuated the presence of the inserts. However, if the specimen had been recently cycled and there had not been sufficient time for air to seep back into the voids, then the deformation of the part due to applied vacuum did not reveal the presence of the inserts.

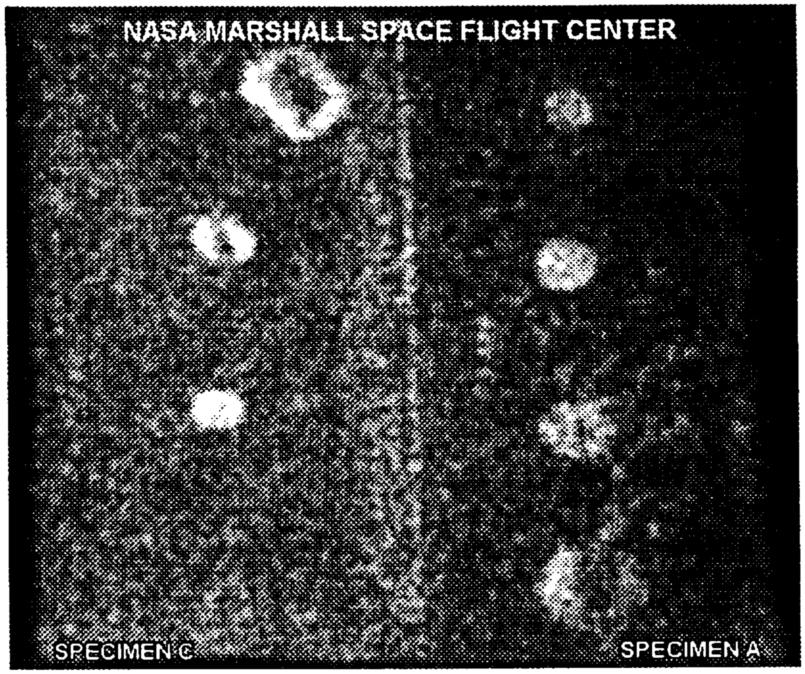


Figure 3.a Insert Detection with Vacuum Excitation, Specimens A and C

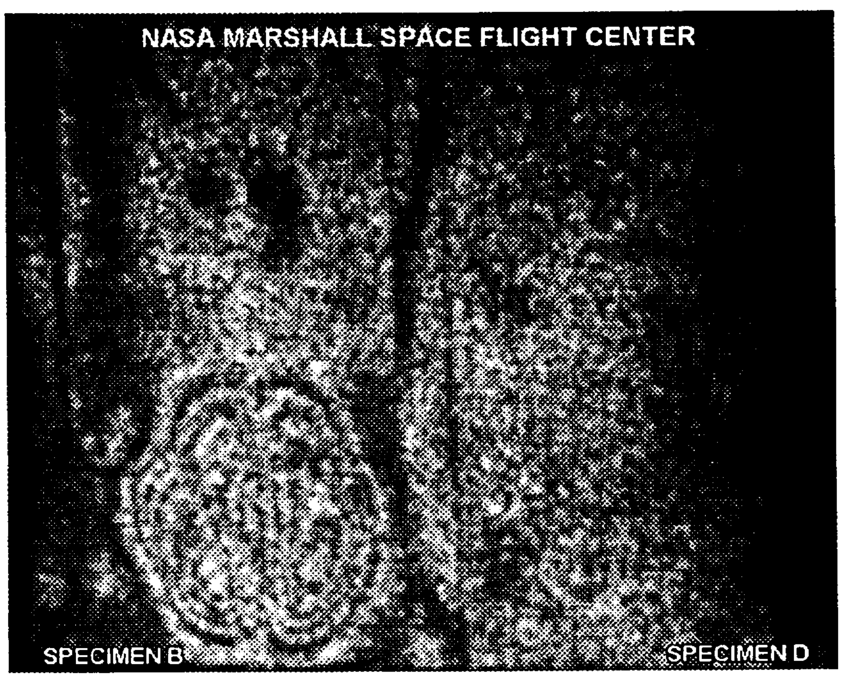


Figure 3.b Insert Detection with Vacuum Excitation, Specimens B and D

3. Thermal Excitation

An alternative method of inspection is to heat the specimen slightly, causing it to expand, and monitor the deformation as the specimen cools. Although the insulative properties of the KFUI layer may prevent detection of flaws below it, an inspection of the first three layers of roving could be conducted before the KFUI had been cast. For this study, an industrial heat gun was used to heat the specimen surface slightly (approximately 5 °C [10 °F]). A reference image was then acquired and subtracted images were obtained as the specimen cooled by natural convection. The resulting shearogram is shown in Figure 4, indicating the detectability of all inserts. A heat lamp may have been used instead of the heat gun, requiring longer excitation times due to the lower heat flux.

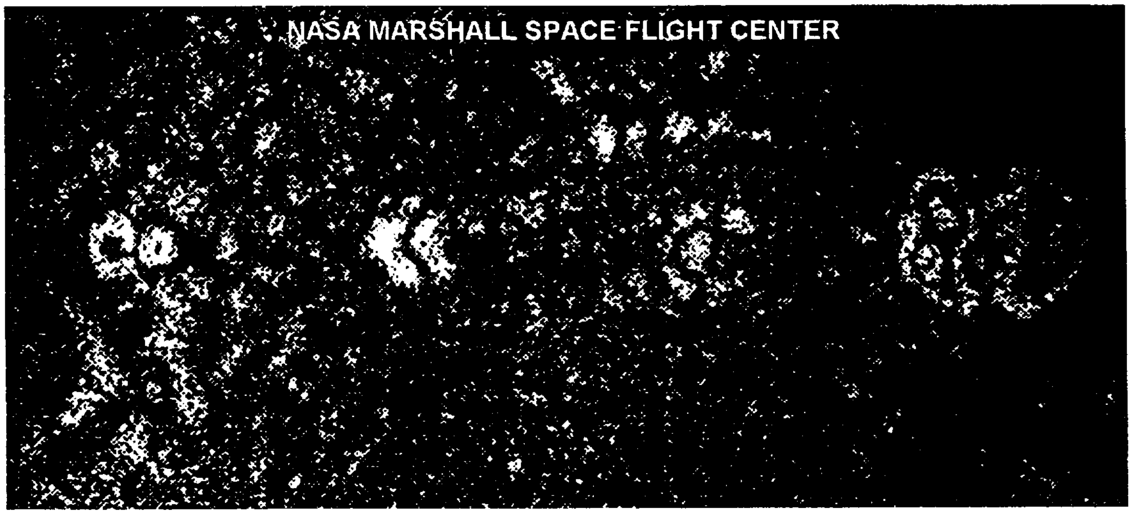


Figure 4. Insert Detection with Thermal Excitation

4. Discussion

A telephone conference concerning THIP inspection was held on 9 October 1996. In attendance were representatives of DuPont, Pratt & Whitney, Marshall Space Flight Center, and the author of this report. It was decided at that time that the primary inspection concern was assuring the bond line integrity between the metal housing and the first three layers of Kevlar roving. Based upon this decision and the results of preliminary coupon testing, it was suggested that the best method for inspection of flight hardware THIP might be conducted with thermal excitation after the first three layers of roving are applied and before the KFUI is cast around it. This technique is less time consuming, labor intensive, and complex than vacuum excitation. Also, vacuum testing would present the difficulty of inspecting surfaces which approach perpendicularity with the vacuum chamber walls. Inclination of the optical head beyond approximately 34° begins to exceed the critical angle for total internal reflection of the illumination laser beam as it passes through the acrylic chamber walls.

B. NDE STANDARD INLET HOUSING

Before the decision was made to finalize thermal excitation as the test method for flight hardware it was recommended that further preliminary testing be conducted on an actual housing. The geometry of the THIP on the housing deviates sufficiently from the flat coupons inspected here as to possibly require a different inspection procedure. These concerns were addressed in the telephone conference and it was decided that an excess housing, not intended for flight, would be primer coated and wrapped with the first three layers of Kevlar roving with simulated unbond inserts imbedded similar to the flat coupons. This test article would be maintained as the NDE standard. The NDE standard housing, when fabricated, was shipped to the MSFC NDE Group. The UAH Research Institute performed the research and development of shearography inspection procedures for THIP inspection based upon the NDE Standard housing.

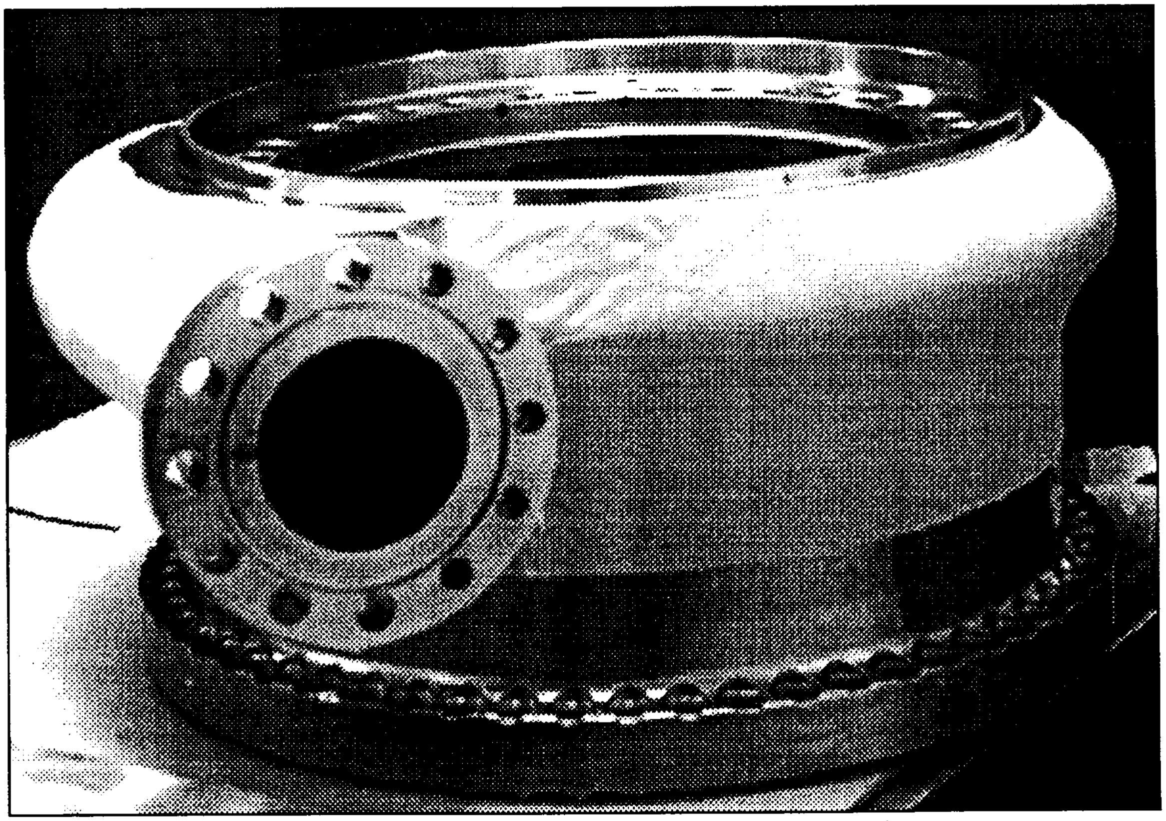


Figure 5. Alternate Turbopump NDE Standard

The Inconel-Kevlar/Urethane NDE Standard inlet housing containing simulated flaws was inspected with electronic shearography. The simulated flaws were representative of unbonds or delaminations of varying sizes in the Alternate Turbopump (AT) housing. DuPont applied the first layer of Kevlar/urethane roving on the Pratt & Whitney housing, including Teflon tape "pillows" to form this NDE standard test article, which is shown in Figure 5. The purpose of these inspections was to determine the appropriate methodology for shearography inspections of the actual flight hardware and to obtain some indication of the associated detectable flaw sizes.

The NASA Marshall Space Flight Center Nondestructive Evaluation and Tribology Branch (EH13) Pratt & Whitney Electronic Holography/Shearography Inspection System (EH/SIS) was used for these inspections. Thermal excitation was provided by means of a hand-held industrial heat gun. The image shearing distance was adjusted to approximately 1/8 inch horizontal at an object distance of approximately 4 feet.

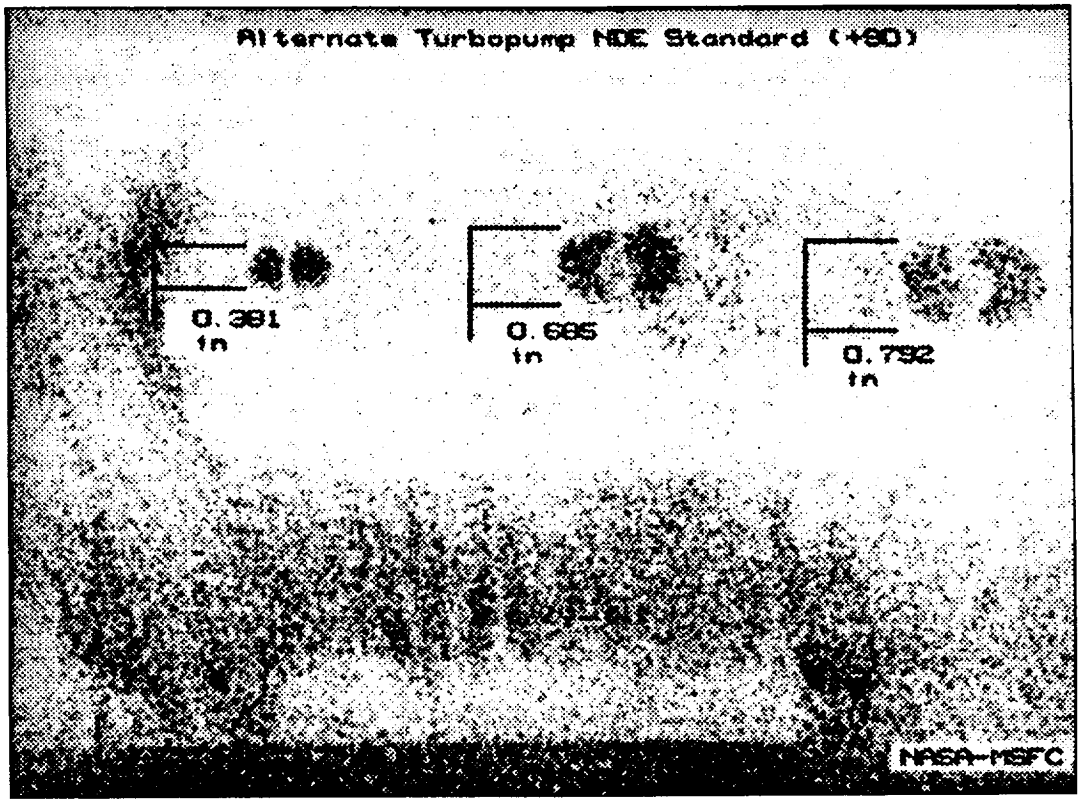


Figure 6. Alternate Turbopump NDE standard shearogram indicating detectability of flaws as small as approximately 3/8 inch.

Figure 6 is a shearogram illustrating the results of these inspections. The shearogram was digitally enhanced to improve reproducibility and interpretability. Image enhancement was performed using CorelPHOTO-PAINT! version 4.00.C1. The following commands were performed: INVERT, REMOVE NOISE (threshold = 0), BRIGHTNESS = -20, CONTRAST = +75.

The three dark "double bull's eye" indications correspond to insert sizes of approximately 3/8 inch, 3/4 inch, and 1 inch. The sizes indicated in the shearogram are as measured by the EH/SIS calibrated video caliper. The dark arc shaped indication to the left of the 3/8 inch indication is believed to be a ply edge. The dark band below the programmed flaws may be due to the curvature as the housing torus joins the cylindrical section, or it may be due to unbonds or excess urethane in this region. Sectioning is suggested if the cause of this indication is to be determined.

III. SOLAR X-RAY IMAGER COMPOSITE TELESCOPE TUBE

Shearography inspections were conducted on the composite telescope tube for the Solar X-ray Imager (SXI) test article after mechanical proof loading. During this loading, titanium flex-tabs, which had been bonded to the composite tube, broke loose. At least one ply of the composite material remained bonded to the flex tabs and separated from the rest of the composite tube. Shearography inspections were conducted to determine how far any remaining delaminations may have propagated beyond visible damage.

The NASA Marshall Space Flight Center Nondestructive Evaluation and Tribology Branch (EH13) Laser Technology, Inc. SC-4000 electronic shearography system was used for these inspections. Thermal excitation was provided by means of a hand-held industrial heat gun. Brent penetrant developer powder was applied to increase the non-specular reflection of laser illumination from the dark composite. Masking tape and paper were used to prevent glare from the highly reflective titanium parts.

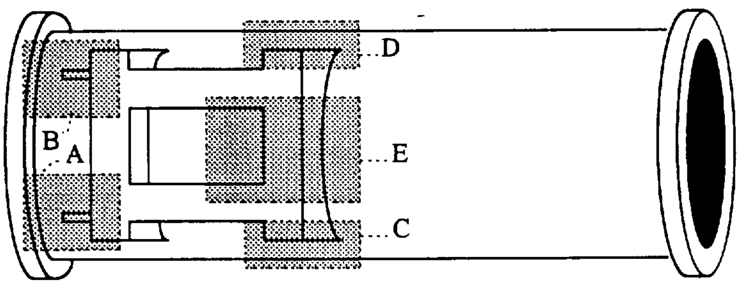


Figure 7. Inspection Locations

Inspections were performed at five locations, as shown schematically in Figure 7. Figures 8 through 12 are shearograms illustrating the results of these inspections. The shearograms were digitally enhanced to improve reproducibility and interpretability. Image enhancement was performed using CorelPHOTO-PAINT! version 4.00.C1. The following commands were performed: INVERT, REMOVE NOISE (threshold = 5), BRIGHTNESS = -40, CONTRAST = +90.

Inspection of the flex pad damage at Location A indicates that delamination may have extended beyond that which is visible directly between the flex pad pin and an adjacent bolt end. The other flex pad damage site, Location B, does not appear to have caused any damage other than that which is visible. No indications were detected at Locations C, D, or E.

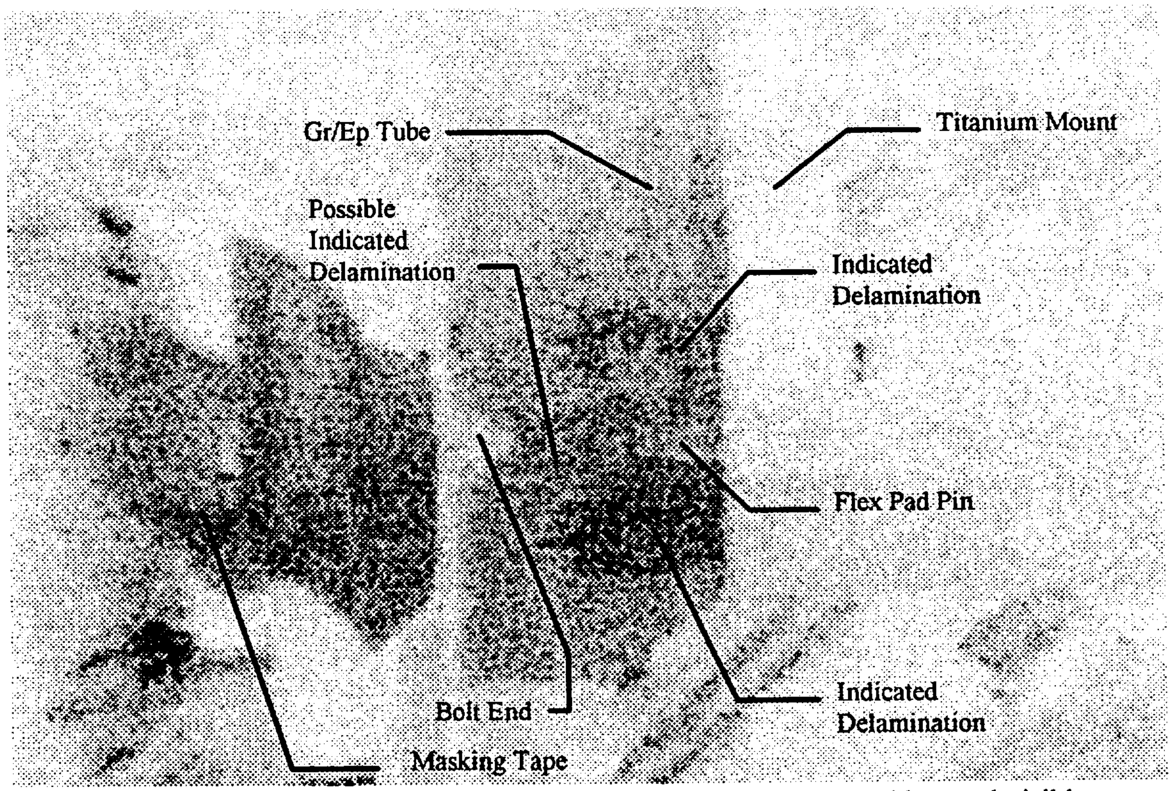


Figure 8. Shearogram of Location A, delamination may extend beyond visible.

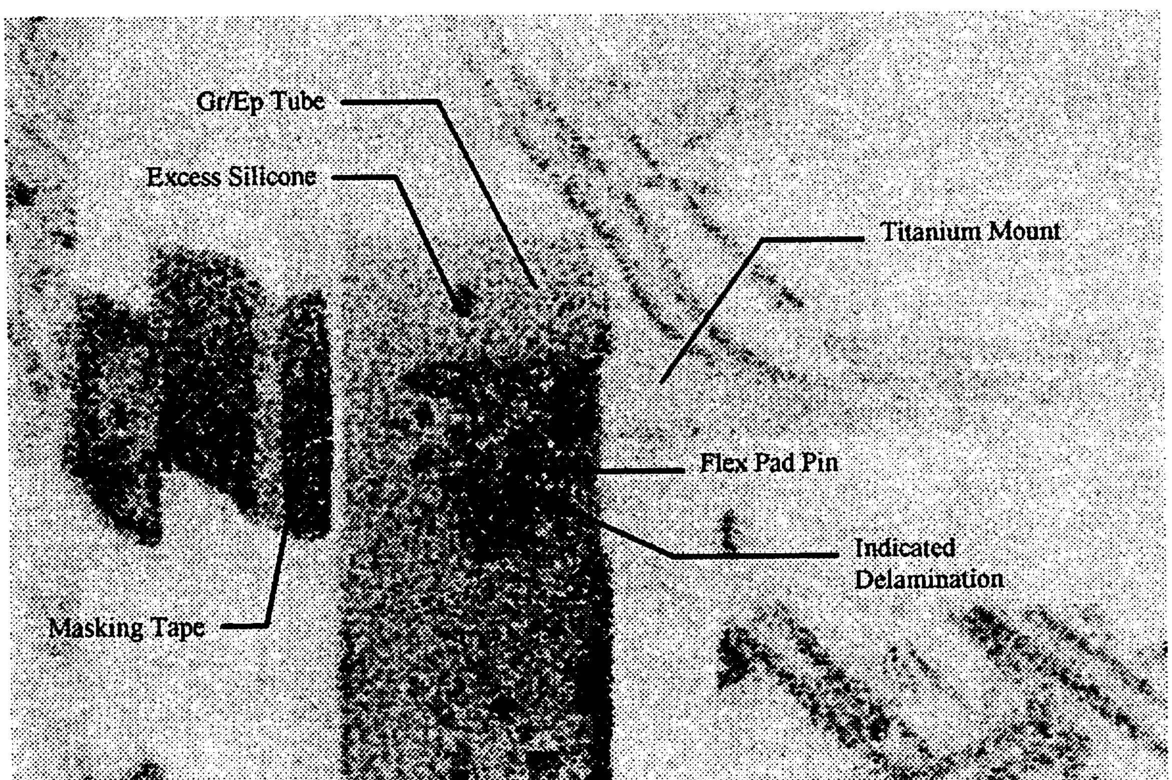


Figure 9. Shearogram of Location B, indication does not extend beyond visible damage.

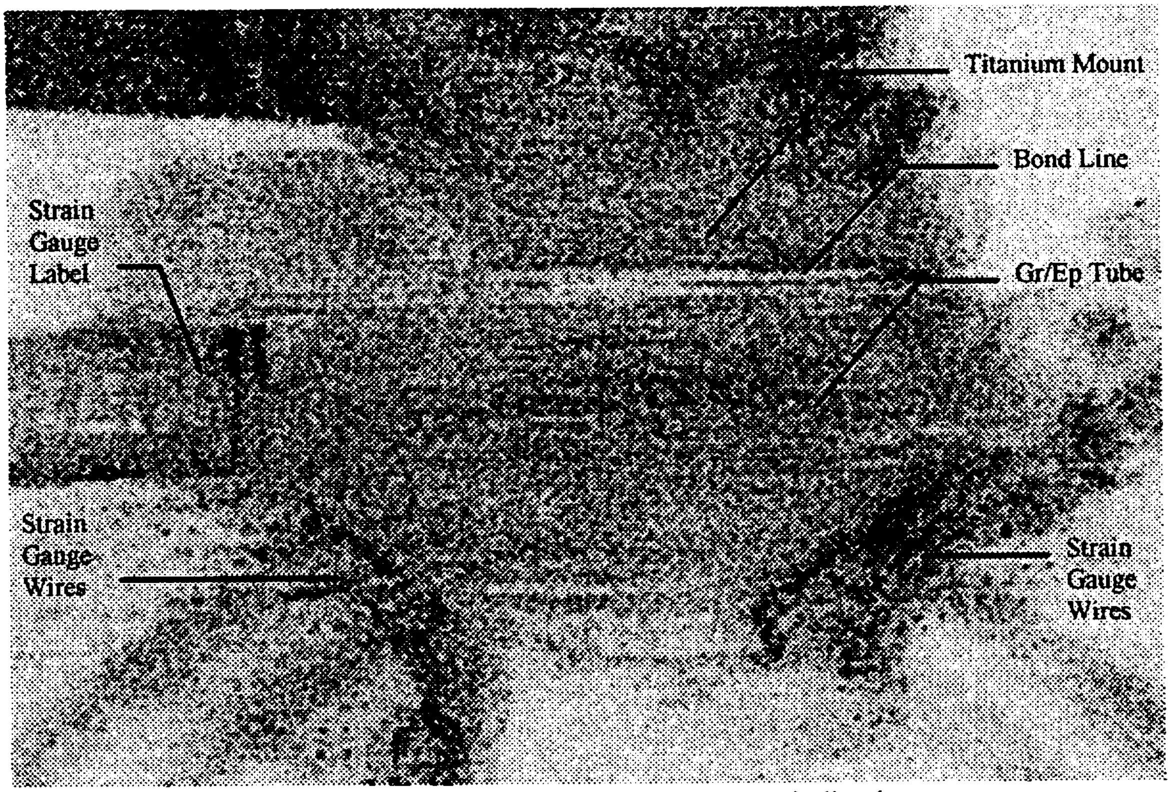


Figure 10. Shearogram of Location C, no indications.

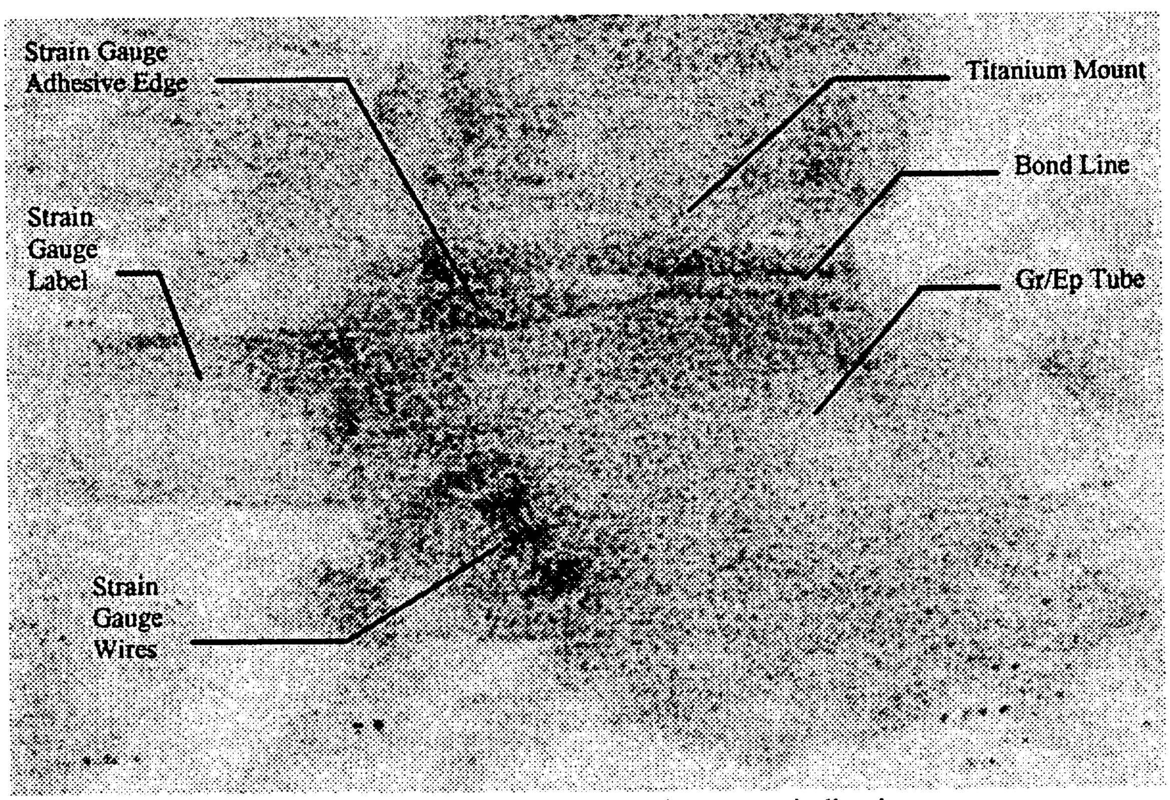


Figure 11. Shearogram of Location D, no indications.

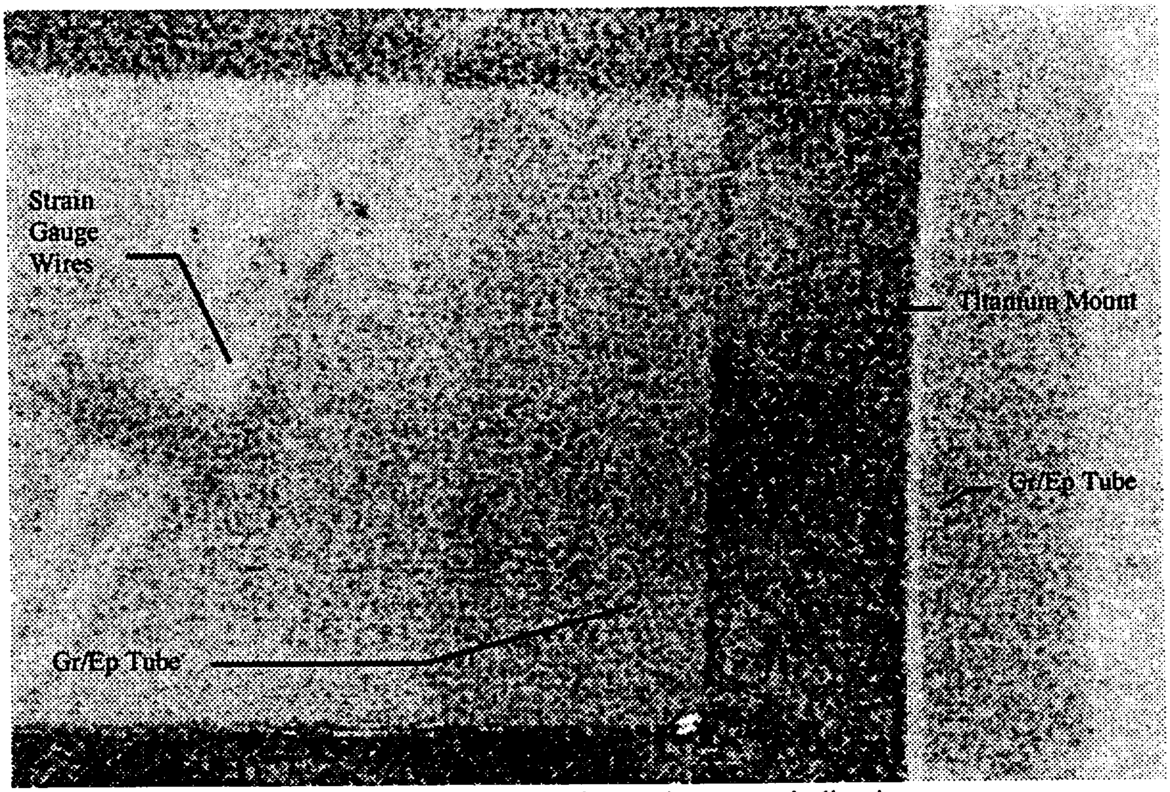


Figure 12. Shearogram of Location E, no indications.

IV. PRATT & WHITNEY EH/SIS SHEAROGRAPHY PROCEDURE

This standardized operating procedure provides instruction for shearography inspection with the Pratt & Whitney Electronic Holography/Shearography Inspection System (EH/SIS). This procedure applies to the use of the EH/SIS control consoles with the shearography optical head only, and does not apply to use with the holography optical head. This procedure is generalized for implementation of any excitation method for static inspection. Suitable excitation methods result in a small differential deformation or gradual deformation of the test article, and are considered as separate procedures.

A. CONVENTIONS:

The font conventions shown in the table below will be used to indicate items in this procedure which correspond to controls, indicators, etc. on the shearography system.

Item	Example
Buttons/Switches/Indicators	**POWER** button
Keyboard Keys	**[ENTER↵]**
Switch Positions	**ON**
PC Monitor Text	`Press Any Key`

Three special keyboard buttons, on the lower right numeric keypad, are labeled with a magic marker, ***[CTR]***, ***[R]***, and ***[L]***, corresponding to the **center**, **right**, and **left** mouse buttons. Note that the mouse button designations do not correspond to the actual positions of these keys relative to each other.

At several times the `ElHolo` software will refer to the **[ENTER↵]** key. This key is labeled RETURN on the EH/SIS keyboard. For consistency with the `ElHolo` software, this guide will refer to this key as the **[ENTER↵]** key.

B. START UP PROCEDURE:

B.1. Press the green back lit **ON** button on the front of the EH/SIS cabinet. This powers up the internal components of the cabinet.

B.2. When the internal PC has booted, the following prompt will appear:

```
Set NumLock off, Hit <Enter> to run ElHolo or <Ctrl>C to
abort.
Press any key to continue...
```

Press the **[NumLock]** button at the upper right of the keyboard so that the green **NumLock** indicator is **OFF**, then press **[ENTER↵]**.

B.3. Turn **ON** the video printer and external video monitor.

B.4. Turn the **Optical Head Selection** knob on the EH/SIS cabinet to the **SHEAR** position.

B.5. Remove the lens cap from the telephoto lens in the optical head.

CAUTION: **LASER!**	*The next step will activate the shearography laser. The shroud should be in place on the optical head before proceeding. Do not look directly into the active laser, either from the front or side openings. Metallic rings, watches, etc. should not be worn when hands are in proximity to the laser beam.*

B.6. Turn the **POWER** key switch on the front of the Adlus Laser Power Supply to the **ON** position. The LEDs next to it should illuminate. Press the **RESET** button next to the key switch. The LEDs should begin flashing, and the laser will begin emitting a green beam if the laser shutter was left open.

CAUTION: **LASER!**	*While working in front of the active laser it is advisable to have the laser shutter* **CLOSED** *when practical. This shutter is accessible from the hinged panel on the left side of the optical head. The shutter is positioned behind a beam steering mirror and directly attached to the laser housing. The shutter is* **OPENED** *and* **CLOSED** *by rotating it. Do not look directly into the laser opening. Do not touch the reflective surface of the steering mirror.*

B.7. Proceed with steps B.8 through B.24 while waiting for the laser diode to warm up and stabilize (approximately 30 minutes) with the laser shutter **CLOSED**.

B.8. Check that the power switch on the right of the Burleigh High Voltage DC Op Amp, on the front of the EH/SIS cabinet, is **ON** (illuminated).

B.9. Check that the **LIMIT** indicator on the Burleigh High Voltage DC Op Amp is **OFF**. If this indicator illuminates at any time press the **RESET** button to its right.

B.10. Turn on available overhead lighting if practical, position the test article 4 to 8 feet in front of the optical head, and position the optical head such that the test article appears in the image on the external video monitor.

B.11. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard, select `Holography` from the left menu on the PC monitor, then press **[ENTER↵].**

B.12. Select `HCAL` from the center menu on the PC monitor, then press **[ENTER↵]**. A freeze frame image will appear on the external video monitor, with an overlaid graphics box.

B.13. Press ***[R]*** on the keyboard to select the lower right corner or upper left corner of the graphics box for movement.

B.14. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard move the graphics box corners such that it includes an area representative of the illumination variations on the test article surface. Regions of the test article which are brighter or darker than those in the graphics box may not appear in subsequent shearograms.

B.15. Press ***[L]*** or **[ENTER↵]** on the keyboard when the desired area is enclosed in the graphics box. The external video monitor will begin flashing a series of still images.

B.16. When the flashing images are replaced with a real time series of interference images and an audible clicking emanates from the phase stepping mirror in the optical head, press ***[L]*** twice to average 4 frames per image, then ***[CTR]***, then

[Ins], then **[Esc]**.

NOTE: *If the video caliper is not going to be used, press* **[ENTER↵]** *then* **[Ins]** *to complete calibration, then skip to step 20. Such may be the case when initially calibrating to overhead lights.*

B.17. A vertical graphics caliper will appear on the external video monitor. Press ***[R]*** on the keyboard to select the lower or upper jaw of the graphics caliper for movement.

B.18. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard, move the graphics caliper jaws such that they bound a portion of the test article of a known size.

B.19. Press ***[L]*** or **[ENTER↵]** on the keyboard when the desired distance is indicated by the graphics caliper on the external video monitor.

B.20. As prompted, enter the magnitude and units of the distance annotated by the graphics caliper. The EH/SIS is now calibrated to the current illumination level and field of view.

B.21. Select `Tool Box` from the left menu.

B.22. Select `Live` from the left menu.

B.23. Adjust focus and zoom by manually adjusting the telephoto lens in the front of the optical head, being careful not to look into the laser.

B.24. Select the appropriate controller for horizontal or vertical image shearing. These controllers are stored on the back of the optical head. Flip the power switch on the right side of the controller to **ON** and use the rocker switch to increase or decrease the amount of image shear as desired. Flip the power switch on the right side of the controller to **OFF** when finished.

NOTE: *Adjusting the image shear to the thickness of the test article or the size of the suspected flaw is a good initial guess if the appropriate degree of image shearing is unknown.*

B.25. When the laser has been allowed sufficient time to warm up and stabilize turn the overhead lights off, open the laser shutter, and repeat steps 10 through 19 to calibrate the image display for laser illumination. The EH/SIS is then ready to begin inspections.

C. STATIC INSPECTION PROCEDURE:

C.1. Select `HOLOGRAPHY` from the left menu and `STATIC` from the center menu.

NOTE: *At any point during the following procedure, the* **[Esc]** *button may be pressed to abort data acquisition and return to the main menu screen. Although the* `STATIC` *routine may continue performing a specific subroutine after the* **[Esc]** *button has been pressed, wait for that subroutine to finish before pressing the* **[Esc]** *button again. Multiple keystrokes may be interpreted as an attempt to exit the system completely. This may result in an inadvertent loss of data.*

C.2. Using the **[↑]** and **[↓]** buttons on the keyboard, move through the list of 4 holography settings. Press the **[*]** key then **[ENTER↵]** at each setting to view a list of options, which are moved through with the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons and selected from by pressing**[ENTER↵]**. If the desired settings are already selected, then press **[Ins]** to accept all of them. Typical settings are shown in the table below:

Red Background Image	NONE
Speckle Averaging	ON
Display Traveling Fringes	NO
Number of Frames to Average	4

The EH/SIS will begin the data acquisition cycle as soon as the **[ENTER↵]** key is pressed in the `Number of Frames to Average` field or the **[Ins]** key is pressed. The external video monitor will begin displaying a real time series of reference images, and an audible clicking will emanate from the phase stepping mirror in the optical head. The PC monitor will prompt:

`Remove Stress, and Press [Ctr] to Acquire Reference Image`

NOTE: *If the phase stepping mirror is not heard and the* **LIMIT** *indicator on the Burleigh High Voltage Power Supply is illuminated, then press the adjacent* **RESET** *button and adjust the unit's* **GAIN** *knob.*

C.3. Select the number of frames to average for the reference image (typically 4) by pressing ***[R]*** to reduce and ***[L]*** to increase.

C.4. With the part at the desired reference state, high temperature for example, press the ***[CTR]*** button to acquire a reference image. If `Speckle Averaging` is **OFF**, then the reference image will be the average of the number of frames indicated in step 3. If `Speckle Averaging` is **ON**, then the reference image will be the result of a frame average of 4 intermediate images, each the frame average of the number of frames indicated in step 3, at 4 different etalon rotations. The computer will then begin displaying real time static shearograms on the external video monitor and the PC monitor will prompt:

`Press [Ctr] to Acquire Frames of Object With Stresses`

NOTE: *Occasionally a bit error will occur in the stepper motor which rotates the etalon, resulting in 2 error messages. Press* **[Esc]** *to clear each error message and continue.*

C.5. Select the number of frames to average for the excited image (typically 4) by pressing the ***[R]*** to reduce and ***[L]*** to increase

C.6. Apply the desired excitation, such as natural convective cooling, and watch the external video monitor for fringe indications. Eventually the images will become incoherent, as the laser phase will drift some over extended periods of time (5 to 10 minutes). At this time the external video monitor will display a mostly gray image which changes little from frame to frame. If no noteworthy results are seen before coherence is lost, then press **[Esc]** to abort and return to the main menu. Otherwise, press ***[CTR]*** to acquire the desired shearogram. Frame and Speckle Averaging will be repeated as for the reference image.

C.7. When data acquisition is aborted or completed, the `ElHolo` main menu screen will reappear on the PC monitor.

D. ANNOTATING SHEAROGRAMS:

D.1. Select `UHolography Utils` from the left `ElHolo` main menu, then select `ANNOTATE IMAGE` from the center command menu.

D.2. The default pointer, VCALIPER, is shown indicating a vertical caliper. Press **[*]** **[ENTER↵]** to display a list of available pointers. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard choose the desired pointer from the list.

D.3. Enter the desired text in the `CAPTION` field. The selected pointer will appear on the external video monitor.

D.4. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard move the pointer to the desired location.

D.5. Press the ***[R]*** button to toggle to the first pointer anchor, then position it using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard.

D.6. Press the ***[R]*** button to toggle to the second pointer anchor, then position it using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard.

D.7. Press **[ENTER↵]** to anchor the pointer.

D.8. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard move the pointer to the desired location.

D.9. Press **[ENTER↵]** to anchor the pointer caption.

D.10. Repeat D.2 through D.9 until all desired pointers and captions have been placed on the shearogram image, then press **[Esc]** to end annotation.

D.11. As prompted, press **[Y]** or **[N]** to accept or cancel annotation.

E. PRINTING SHEAROGRAMS:

E.1. Press **MEMORY IN** then **PRINT** on the Sony Video Printer or remote control.

E.2. Wait for the print to appear in the output opening.

NOTE: *If the* **ALARM** *indicator on the front of the printer illuminates, then a new paper packet needs to be added (the door beneath the print opening) and/or a new toner cartridge is required (the door to the left of the print opening). It is advisable to change toner and add a complete paper packet at the same time.*

F. SAVING SHEAROGRAM FILES:

F.1. Select `HOLOGRAPHY` from the left `ElHolo` main menu, then select `ISAVE` from the center menu.

F.2. When the `ISAVE IMAGE` box appears, the cursor will default to the `FILE NAME` field. Use the **[←]** key to move to the `DIRECTORY` field.

F.3. Use the **[Delete]** or **[BkSpc]** key to erase the entire default path from this field, then press **[ENTER↵]**.

F.4. An error message will appear stating that no path was selected. Press **[ENTER↵]** to display a list of available drives. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard highlight the desired drive then press **[ENTER↵]**.

NOTE: *The directory list will contain directories* `A:` *through* `Z:` *although not all of these drives will be available. Choose one of the following drives:*
`A:` *3.5" floppy* `B:` *5.25" floppy* `C:` *hard disk* `D:` *optical disk*

F.5. A list of directories on the selected drive will appear. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard highlight the desired directory then press **[ENTER↵]**.

F.6. The selected drive and directory will appear in the `DIRECTORY` field. Use the **[→]** key to move to the `FILE NAME` field, type in the desired file name, then press **[ENTER↵]**.

F.7. The cursor will move to the COMMENT field. Type a comment to appear on the PC monitor when the file is later loaded, then press **[ENTER↵]**. For example, the specimen designation and shearing distance may be noted here.

G. LOADING SHEAROGRAM FILES:

G.1. Select HOLOGRAPHY from the left ElHolo main menu, then select ILOAD from the center menu.

G.2. When the ENTER FILE NAME box appears, the cursor will default to the FILE NAME field. Use the **[←]** key to move to the DIRECTORY field.

G.3. Use the **[Delete]** or **[BkSpc]** key to erase the entire default path from this field, then press **[ENTER↵]**.

G.4. An error message will appear stating that no path was selected. Press **[ENTER↵]** to display a list of available drives. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard highlight the desired drive then press **[ENTER↵]**.

NOTE: *The directory list will contain directories* A: *through* Z: *although not all of these drives will be available. Choose one of the following drives:*
A: *3.5" floppy* B: *5.25" floppy* C: *hard disk* D: *optical disk*

G.5. A list of directories on the selected drive will appear. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard highlight the desired directory then press **[ENTER↵]**.

G.6. The selected drive and directory will appear in the DIRECTORY field. Use the **[→]** key to move to the FILE NAME field.

G.7. Use the **[Delete]** or **[BkSpc]** key to erase the entire default path from this field, then press **[ENTER↵]**.

G.8. An error message will appear stating that no file name was selected. Press **[ENTER↵]** to display a list of available drives. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard highlight the desired file name then press **[ENTER↵]** twice.

G.9. The stored image will appear on the external video monitor and the associated comment will be briefly displayed on the PC monitor while the file loads.

H. SHUT DOWN PROCEDURE:

H.1. At the `ElHolo` main menu, press **[F10]** to exit the software and return to DOS.

H.2. Press **[Y]** when prompted to confirm exit command.

H.3. Turn the **Optical Head Selection** knob on the EH/SIS cabinet to the **OFF** position.

H.4. Turn **OFF** the external video monitor and video printer.

H.5. Press red back lit **OFF** button on the front of the EH/SIS cabinet. This powers down the internal components of the cabinet.

H.6. Turn the **POWER** key switch on the front of the Adlus Laser Power Supply, beneath the optical head on the tripod, to the **OFF** position.

H.7. Turn the laser output shutter to the **CLOSED** position.

H.8. Replace the lens cap on the telephoto lens inside the optical head.

I. REFERENCE:

Electronic Holography/Shearography Inspection System Commercial Manual, United Technologies Corporation, Pratt & Whitney, Government Engines & Space Propulsion, 199?.

V. LASER TECHNOLOGY INC. SC-4000 SHEAROGRAPHY PROCEDURE

This standardized operating procedure provides instruction for shearography inspection with the Laser Technology Inc. SC-4000 Advanced Shearography System. This procedure applies to the use of the SC-4000 control console with the SC-50Z shearography optical head modified for variable shear angle. This procedure is generalized for implementation of any excitation method for static inspection. Suitable excitation methods result in a small differential deformation or gradual deformation of the test article, and are considered as separate procedures.

A. CONVENTIONS:

The font conventions shown in the table below will be used to indicate items in this guide which correspond to controls, indicators, etc. on the shearography system.

ITEM	EXAMPLE
Buttons/Switches/Indicators	**POWER** button
Keyboard Keys	**[ENTER↵]**
Switch Positions	**ON**
PC Monitor Text	`Press Any Key`

At several times the **[ENTER↵]** key will be referred to. This key may be labeled **[RETURN↵]** on the keyboard plugged in to the SC-4000.

B. START UP PROCEDURE:

B.1. Ensure that the coaxial video cable is properly connected to the **VIDEO IN** BNC connector on the back of the SC-4000 console and to the **VIDEO** BNC connector on the back of the SC-50Z camera.

B.2. Ensure that the 120VAC/12VDC power supply for the SC-50Z camera is properly connected to the **POWER** connector on the back of the camera and a 120VAC outlet. The **POWER** indicator lamp on the back of the camera should illuminate.

B.3. Ensure that keyboard cable is properly connected to the back of the SC-4000 console.

B.4. Ensure that the remote control cable is properly connected to the back of the SC-4000 console.

B.5. Ensure that the PC style power cable is properly connected to the back of the SC-4000 console.

B.6. Ensure that the PC style power cable is properly connected to the back of the laser power supply.

B.7. Ensure that the laser power cable is properly connected to the back of the laser power supply and the SC-50Z camera.

B.8. Remove the lens cap from the telephoto lens on the front of the SC-50Z camera.

CAUTION: **LASER!**	*The next step will activate the shearography laser. The main laser shutter on the back of the SC-50Z camera and the auxiliary laser shutter on the side of the SC-50Z camera should both be in the* **CLOSED** *position before proceeding. Do not look directly into the active laser. Metallic rings, watches, etc. should not be worn when hands are in proximity to the laser beam.*

B.9. Turn the **POWER** key switch on the front of the Laser Power Supply to the **ON** position. The LEDs next to it should illuminate. Press the **RESET** button next to the key switch. The LEDs should begin flashing, and the laser will begin emitting a green beam if both laser shutters were left open.

CAUTION: **LASER!**	*While working in front of the active laser it is advisable to have both laser shutters* **CLOSED** *when practical. Do not look directly into the laser opening.*

B.10. Wait for the laser diode to warm up and stabilize (approximately 30 minutes) with both laser shutters **CLOSED**.

B.11. Turn **ON** the SC-4000 console and wait for the system to boot up. The **POWER** switch is located on the back of the console. Viewing the console from the front, the **POWER** switch is on the lower left rear corner. Viewing the console from behind, the **POWER** switch is on the lower right corner.

B.12. Turn **ON** available overhead lighting (if practical), position the test article 4 to 8 feet in front of the optical head, and position the optical head such that the test article appears in the image on the SC-4000 console video monitor.

B.13. Press the **[MENU]** button on the SC-4000 console, then using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console select `CAMERA SETUP` from the menu on the SC-4000 console video monitor, then press **[ENTER↵]** on the keyboard or SC-4000 console.

B.14. Using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console, select `IRIS/FOCUS` from the `CAMERA SETUP` menu on the PC monitor, then press **[ENTER↵]** on the keyboard or SC-4000 console.

B.15. Using the **[↑]**, and **[↓]** buttons on the keyboard or on the SC-4000 console, adjust the iris such that the surface of the test article is visible in the SC-4000 console video monitor.

B.16. Adjust the **HORIZONTAL** and **VERTICAL SHEAR** micrometers on the side of the SC-50Z camera such that all discernible image shear is removed.

B.17. If practical, place a focusing target on the specimen surface within the field of view such that it is visible in the SC-4000 console video monitor.

B.18. Using the **[←]**and **[→]** buttons on the keyboard or on the SC-4000 console, adjust the focus such that the focusing target is clearly read in the SC-4000 console video monitor.

B.19. Adjust the **HORIZONTAL** and **VERTICAL SHEAR** micrometers on the side of the SC-50Z camera such that the desired amount of image shear is obtained.

NOTE: *Adjusting the image shear to the thickness of the test article or the size of the suspected flaw is a good initial guess if the appropriate degree of image shearing is unknown.*

B.20. If a focusing target was used, remove it from the specimen surface.

B.21. When the laser diode has been allowed sufficient time to warm up, open the main and auxiliary laser shutters.

B.22. Using the **[↑]**, and **[↓]** buttons on the keyboard or on the SC-4000 console, adjust the iris such that the laser speckle pattern on the surface of the test article is visible in the SC-4000 console video monitor.

B.23. Adjust the **LASER ZOOM** on the side of the SC-50Z camera such that the laser beam illuminates the entire field of view visible in the SC-4000 console video monitor, and minimize the illumination outside the field of view.

B.24. Using the **[↑]**, and **[↓]** buttons on the keyboard or on the SC-4000 console, adjust the iris again if necessary.

B.25. Press the **[ESC]** button on the keyboard or on the SC-4000 console to return to the main menu on the SC-4000 console video monitor.

B.26. Using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console, select `IMAGING FUNCTIONS` from the menu on the SC-4000 console video monitor, then press **[ENTER↵]** on the keyboard or SC-4000 console.

B.27. Using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console, select `PHASE IMAGING` from the `IMAGING FUNCTIONS` menu on the PC monitor, then press **[ENTER↵]** on the keyboard or SC-4000 console.

B.28. Using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console, toggle `PHASE IMAGING to OFF or ON` as required, then press **[ENTER↵]** on the keyboard or SC-4000 console.

B.29. Press the **[ESC]** button on the keyboard or on the SC-4000 console to exit all menus on the SC-4000 console video monitor.

C. STATIC INSPECTION PROCEDURE:

C.1. With the specimen at the desired reference state of stress, i.e. high temperature, press the **[REFRESH]** button on the SC-4000 console or remote control. A reference interference image will be acquired, and frame rate live video interference images will be compared to this reference. A series of real time shearograms will appear on the SC-4000 console video monitor.

C.2. Apply the desired excitation, i.e. natural convective cooling, and watch the SC-4000 console video monitor for fringe indications. Eventually the images will become incoherent. At this time the SC-4000 console video monitor will display a mostly gray image which changes little from frame to frame.

C.3. If no noteworthy results are seen before coherence is lost, then press **[FREEZE]** to end image processing. Otherwise, press **[FREEZE]** to acquire the desired shearogram.

C.4. When data acquisition is aborted or completed, the resultant shearogram will appear in the SC-4000 console video monitor.

D. PRINTING SHEAROGRAMS:

D.1. Press the **[MEMORY IN]** button, then the **[PRINT]** button on the Sony Video Printer or remote control.

D.2. Wait for the print to appear in the output opening.

NOTE: *If the* **ALARM** *indicator on the front of the printer illuminates, then a new paper packet needs to be added (the door beneath the print opening) and/or a new toner cartridge is required (the door to the left of the print opening). It is advisable to change toner and add a complete paper packet at the same time.*

E. SAVING SHEAROGRAM FILES:

E.1. Press the **[MENU]** button on the SC-4000 console, then using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console select `FILE` from the menu on the SC-4000 console video monitor, then press **[ENTER↵]** on the keyboard or SC-4000 console.

E.2. Using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console, select `SAVE` from the `FILE` menu on the SC-4000 console video monitor, then press **[ENTER↵]** on the keyboard or SC-4000 console.

E.3. As prompted, type a comment which will identify the shearogram, using the keyboard, then press **[ENTER↵]** on the keyboard or SC-4000 console.

E.4. Press the **[ESC]** button on the keyboard or on the SC-4000 console to exit all menus on the SC-4000 console video monitor.

F. LOADING SHEAROGRAM FILES:

F.1. Press the **[MENU]** button on the SC-4000 console, then using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console select `FILE` from the menu on the SC-4000 console video monitor, then press **[ENTER↵]** on the keyboard or SC-4000 console.

F.2. Using the **[↑]** and **[↓]** buttons on the keyboard or on the SC-4000 console, select `LOAD` from the `FILE` menu on the SC-4000 console video monitor, then press **[ENTER↵]** on the keyboard or SC-4000 console.

F.3. Using the **[←]**, **[→]**, **[↑]**, and **[↓]** buttons on the keyboard or on the SC-4000 console, select the desired file name, then press **[ENTER↵]** on the keyboard or SC-4000 console. The shearogram will appear on the SC-4000 console video monitor.

F.4. Press the **[ESC]** button on the keyboard or on the SC-4000 console to exit all menus on the SC-4000 console video monitor.

G. SHUT DOWN PROCEDURE:

G.1. Close the main and auxiliary laser shutters on back and side of the SC-50Z camera.

G.2. Replace the lens cap on the front of the SC-50Z camera.

G.3. Turn the **POWER** key switch on the front of the laser power supply to the **OFF** position.

G.4. Turn **OFF** the SC-4000 console and video printer.

G.5. Unplug the 120VAC/12VDC power supply for the SC-50Z camera.

H. REFERENCE:

SC-4000 Advanced Shearography System Operations Manual, Laser Technology, Inc., 1993.

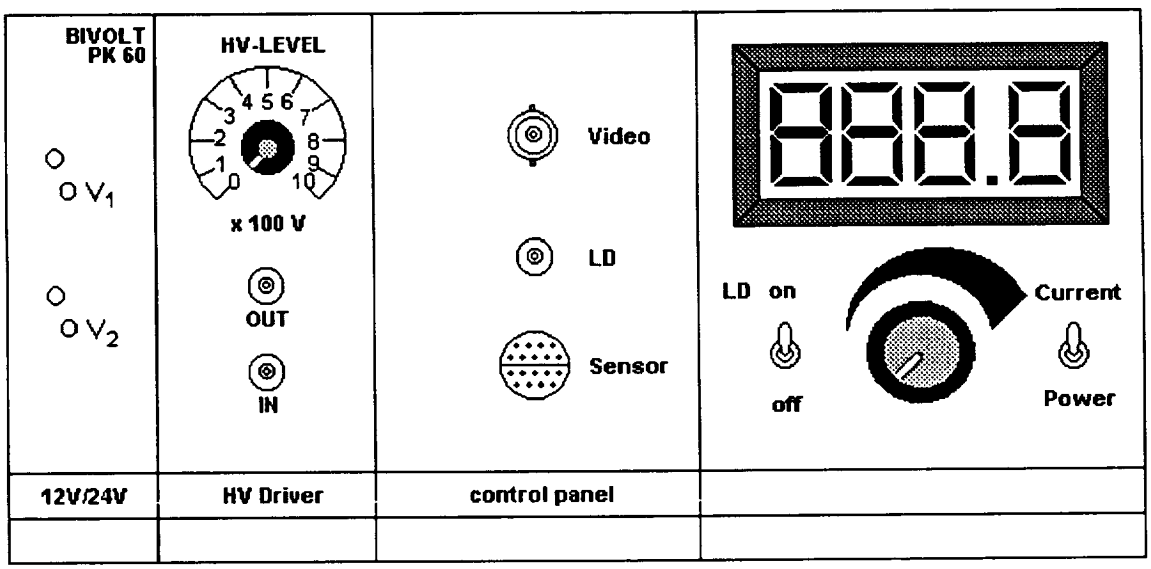
VI. ETTEMEYER SHS-94 ISTRA SHEAROGRAPHY PROCEDURE

This standardized operating procedure provides instruction for shearography inspection with the Ettemeyer SHS-94 shearography system. This procedure applies to the use of the SHS-94 optical head and control console with Istra software. This procedure is generalized for implementation of any excitation method for static inspection.

Suitable excitation methods result in a small differential deformation or gradual deformation of the test article, and are considered as separate procedures.

A. CONTROLS:

The controls on the front of the Ettemeyer SHS-94 cabinet, beneath the keyboard, are illustrated below. These controls will be referred to as labeled throughout this procedure.



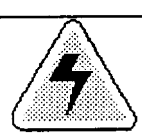
B. START UP PROCEDURE:

B.1. Connect one end of the small black power cable to the **OUT** socket on the **HV Driver** section of the SHS-94 controls.

B.2. Connect the associated end of the large gray video cable to the **Sensor** socket on the **control panel** section of the SHS-94 controls, taking care to align the pins properly.

B.3. Connect the other end of the small black power cable to the matching socket on the back of the optical head.

B.4. Remove the red safety plug from video socket on the back of the optical head.



CAUTION!

With the red safety plug removed, the power contacts for the camera are exposed and sensitive to static discharge. Care should be taken not to touch the exposed contacts.

B.5. Carefully connect the large gray video cable to the matching socket, from which the red safety plug has been removed, on the back, taking care to align the connectors properly.

B.6. Turn on the main power for the SHS-94 console. This switch is inside the transparent door on the front of the console next to the disk drives.

B.7. Wait for the PC to boot up. Windows will start, then ISTRA and Movie Machine.

B.8. Click on the ISTRA window so that its title bar is highlighted.

NOTE: *The remote control keypad will not function properly if Windows has not set its focus to ISTRA, as indicated by a highlighted title bar.*

B.9. Press the LIVE IMAGE button on the remote control.

CAUTION: LASER!	*The next step will activate the shearography laser. The infrared beam will be invisible, so adequate safety precautions should be taken. Do not look directly into the active laser. Metallic rings, watches, etc. should not be worn when hands are in proximity to the laser beam.*

B.10. Set the **LD on/off** switch on the front of the SHS-94 console to the **on** position. The LCD display above it should become active.

B.11. Set the **Current/Power** switch on the front of the SHS-94 console to the **Current** position. The LCD display above it should display the current supplied to the shearography laser diode in milliamperes.

B.12. Adjust the knob between the **LD on/off** switch and the **Current/Power** switch on the front of the SHS-94 console so that the diode current indicator reads 50 to 100 milliamperes.

C. CALIBRATION PROCEDURE:

C.1. Position the test article 1 to 4 feet in front of the optical head, and position the optical head such that the test article appears in the image in the Movie Machine window.

C.2. Focus the image by turning the brass collar on the front of the optical head.

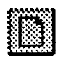
C.3. Press the **REFERENCE** button on the remote control.

C.4. Excite the test article similar to that which will be used for later analysis. A fringe pattern should appear in the Movie Machine window.

C.5. Press the **CREATE PHASE MAP** button on the remote control.

C.6. Remove the excitation from the test article and wait for ISTRA to complete image processing.

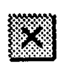
C.7. Click on the ISTRA window so that its title bar is highlighted.

C.8. Click on the  NEW BORDER button.

C.9. Select the desired border geometry by clicking on the following appropriate button:

C.10. Click and drag to draw the border on the image.

C.11. Click on the  **LINE MOVE** or  **POINT MOVE** button to edit the border geometry, then click and drag on the border to make adjustments.

C.12. Click on the  **SET REGION** button, then click inside or outside of the border depending upon which is the region of interest.

NOTE: The point where the region is set will be assumed to have zero slope for fringe counting analysis. This point should be selected with care if absolute, rather than relative, surface deformation is to be measured.

C.13. Click on the  **UPPER LEFT CORNER SCALE** button, then click on the first calibration point.

C.14. Enter the appropriate coordinates in actual dimensions on the test article.

C.15. Click on the  **LOWER RIGHT CORNER SCALE** button, then click on the second calibration point.

C.16. Enter the appropriate coordinates in actual dimensions on the test article.

C.17. Click on the  **UPDATE MOVIE MACHINE** button to transfer border information to Movie Machine.

D. SAVING SHEAROGRAM IMAGES:

ISTRA shearogram images may be saved as 2PI images for later use only by ISTRA, or as TIFF or Windows Bitmap files for later use with other software.

D.1. SAVING 2PI OR TIFF IMAGES:

Phase images, video images, or interference patterns may be saved as 2PI or TIFF images.

From the menu bar at the top of the ISTRA window, select **Image**. Then select **Save Image...** from the pull down menu.

Standard Windows dialog boxes will prompt for the file name.

D.2. SAVING WINDOWS BITMAP IMAGES:

Graphics images, such as contour lines, profiles, or 3D plots, may be saved as Windows Bitmap images.

From the menu bar at the top of the ISTRA Graphics window, select **Edit**. Then select **Copy** from the pull down menu.

From the Windows **Program Manager**, open the Accessories program group then launch **Paint Brush**.

From the menu bar at the top of the Paint Brush window, select **Edit**. Then select **Paste** from the pull down menu.

NOTE: *If the Paint Brush image is inappropriately sized for the data pasted onto it, select* **Options** *then* **Image Attributes** *and adjust the height and width to fit the pasted data. This may require several adjustments to determine the appropriate settings.*

From the menu bar at the top of the Paint Brush window, select **File**. Then select **Save** from the pull down menu.

Standard Windows dialog boxes will prompt for the file name.

E. PRINTING SHEAROGRAM IMAGES:

E.1. PRINTING TIFF IMAGES:

Phase images, video images, or interference patterns which have been saved as 2PI or TIFF images may not be printed from within ISTRA. Another image processing program must be used to print the saved image files. Alternatively, TIFF images may be imported into word processing programs and included in inspection reports.

E.2. PRINTING WINDOWS BITMAP IMAGES:

Graphics images, such as contour lines, profiles, or 3D plots, may be printed from within ISTRA or from another image processing program if saved as Windows Bitmap images. Alternatively, Windows Bitmaps may be imported into word processing programs and included in inspection reports.

From the menu bar at the top of the ISTRA Graphics window, select **Edit**. Then select **Print** or **Print (Draft)** from the pull down menu.

F. LOADING SHEAROGRAM IMAGES:

Only ISTRA phase images, video images, or interference patterns images which have been saved as 2PI files may be loaded back into ISTRA for further shearography analysis.

From the menu bar at the top of the ISTRA window, select **Image**. Then select **Load Image...** from the pull down menu.

Standard Windows dialog boxes will prompt for the file name.

G. SHUT DOWN PROCEDURE:

G.1. Exit Movie Machine, ISTRA, and Windows.

G.2. Adjust the knob between the **LD on/off** switch and the **Current/Power** switch on the front of the SHS-94 console so that the LCD above it reads 0 milliamperes.

G.3. Set the **LD on/off** switch on the front of the SHS-94 console to the **off** position. The LCD above it should cease activity.

G.4. Turn off the main power for the SHS-94 console. This switch is inside the transparent door on the front of the console next to the disk drives.

G.5. Disconnect the small black power cable from the optical head.

G.6. Carefully disconnect the large gray video cable from the optical head.

CAUTION!	*With the power cable removed the power contacts for the camera are exposed and sensitive to static discharge. Care should be taken not to touch the exposed contacts.*

G.7. Replace the red safety plug in the optical head camera power connector.

G.8. Assure that the optical head, cables, and console are left in a safe position which will not allow them to be easily knocked over, or which will obstruct walkways.

G.9. Take care to protect the fragile lenses on the front of the optical head while the system is not in use.

H. REFERENCE:

SC-4000 Advanced Shearography System Operations Manual, Laser Technology, Inc., 1993.