Laser Shearography Inspection of TPS (thermal protection system) cork on RSRM (reusable solid rocket motors)

Mike Lingbloom*, Jim Plaia*, John Newman**
*ATK Thiokol Inc. Brigham City, UT, USA 435-863-4711
** Laser Technology Inc. Norristown,PA, USA 610-631-5043

ABSTRACT

Laser Shearography is a viable inspection method for detection of de-bonds and voids within the external TPS (thermal protection system) on to the Space Shuttle RSRM (reusable solid rocket motors). Cork samples with thicknesses up to 1 inch were tested at the LTI (Laser Technology Incorporated) laboratory using vacuum-applied stress in a vacuum chamber. The testing proved that the technology could detect cork to steel un-bonds using vacuum stress techniques in the laboratory environment. The next logical step was to inspect the TPS on a RSRM.

Although detailed post flight inspection has confirmed that ATK Thiokol's cork bonding technique provides a reliable cork to case bond, due to the Space Shuttle Columbia incident there is great interest in verifying bond-lines on the external TPS. This interest provided an opportunity to inspect a RSRM motor with Laser Shearography.

This paper will describe the laboratory testing and RSRM testing that has been performed to date. Descriptions of the test equipment setup and techniques for data collection and detailed results will be given. The data from the test show that Laser Shearography is an effective technology and readily adaptable to inspect a RSRM.

INTRODUCTION

In the RSRM program, a repeatable and reproducible NDT inspection method has become increasingly important for the inspection of the TPS bond-line. The Space Shuttle booster or RSRM has a TPS system that consists of strips of cork and a filler of RT455. The cork strips are bonded to the RSRM case and are used to create a cable tray for heater and instrumentation cables. The cables are then covered with a cork filled epoxy material called RT455. Figure 1 shows the TPS configuration.

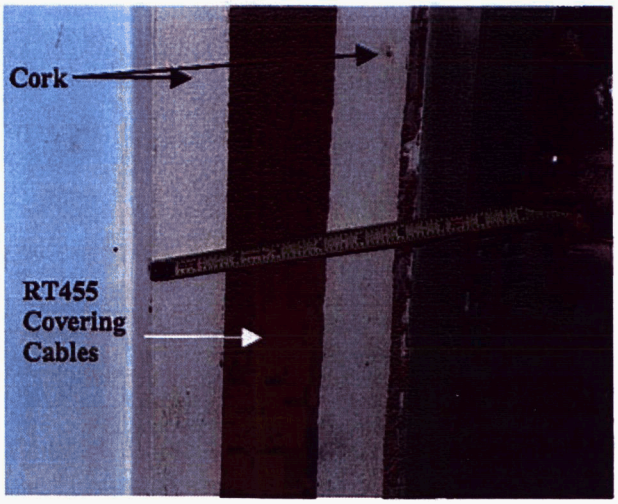

Figure 1 TPS Configuration

The existing method of tap testing along with post flight inspection of the cork has long provided data that validates the cork to case bond line has been reliable, however it is understood that the tap test inspection is operator sensitive and does not provide a permanent record of the inspection. The quality of the TPS bond line has become more of an issue since the Space Shuttle Columbia incident has demonstrated the potential effects of debris on the orbiter.

In pursuing the best NDT inspection to meet the inspection and production needs of the RSRM program, the following course of action is underway.

1. Cork samples with attempted un-bonds were built and sent to several vendors
2. Evaluation of testing results and technical evaluations were used to determine what technology and vendor to select
3. A RSRM test motor was identified and a contract was awarded for testing the motor
4. Capability studies to determine minimum flaw size are in work including creating controlled flaws in test samples

LABORATORY TESTING AND TECHNOLOGY EVALUATIONS

NDT inspection of the TPS bond line has been considered in the past and equipment had been previously evaluated and tested. Several of the technologies previously evaluated with poor results were discounted for this testing. These technologies include pulse echo ultrasonic from the cork side, acoustic emission, IR thermography, and automated tap testers.

Several emerging technologies that have promise such as X-ray backscatter and Terahertz imaging were also given consideration. These technologies were determined to be more capable than shearography when minimum flaw size imaging is concerned, however when evaluated for inspection throughput they were determined to be too slow for implementation into RSRM production flow. There was also concern over the immaturity of the emerging technologies. There is simply no long-term track record illustrating the reliability of the new technologies for implementation into a production environment.

It was determined that Electronic Shearograpy using a vacuum loading stress method would be the method to pursue for RSRM TPS bond line and void inspections. Several sets of cork samples were manufactured with intended un-bonds of various sizes at the steel to cork bond, figure 2. The samples were all 4 inch by 4 inch wide. The samples had 1inch thick cork bonded to ¼ inch thick steel substrate using the same adhesive that is used for RSRM production. Un-bonds were attempted by simply not applying the adhesive in a predetermined area. The planned un-bond sizes were ½ inch, 1 inch, and 2 inch. These samples were sent to interested vendors for laboratory testing with LTI the only vendor returning significant results.

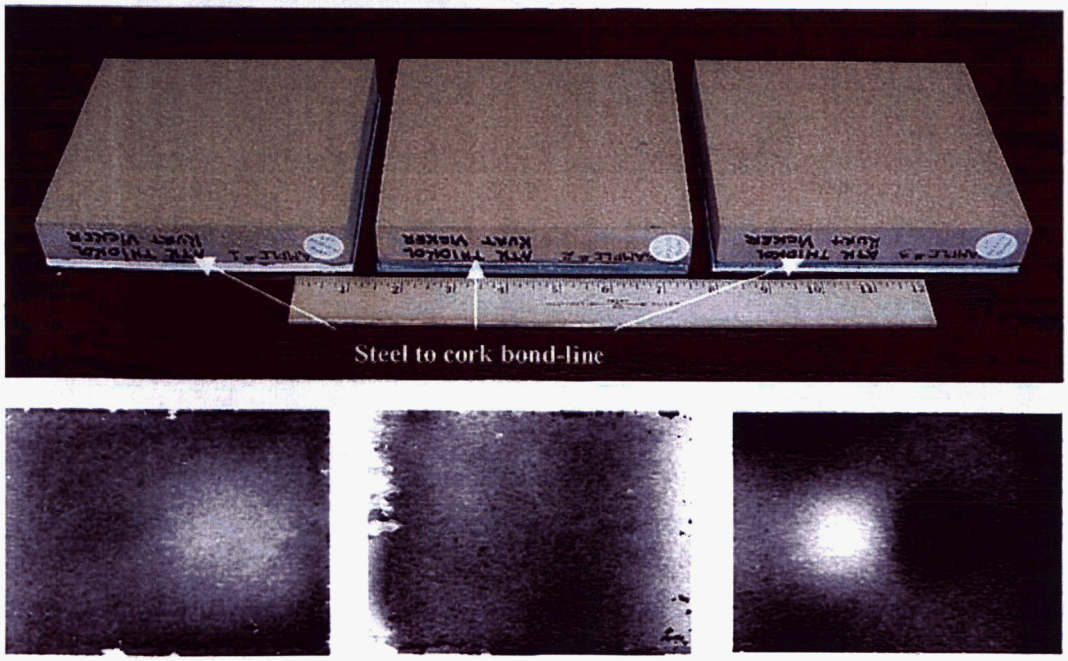

Figure 2 1" Cork un-bond samples

The test results that were returned from LTI showed indications on the 2 inch un-bond and 1 inch un-bond samples but not on the ½ inch un-bond sample, figure 2. After the samples were returned from LTI, they were inspected with a pulse-echo ultrasonic method from the steel side. The ultrasonic inspection detected un-bonds on the 1inch and 2 inch un-bond samples, but did not get an indication on the ½ inch un-bond sample. The ultrasonic testing also sized the two un-bonds at about ½ inch smaller than the intended size. This indicates the method for creating the un-bonds is not reliable for controlling the size of un-bonds. These samples will be dissected at a later date to verify the presence and the size of the un-bonds. There was also one other ¼ inch thick cork test sample with known flaw sizes as small as ¼ inch diameter that was evaluated with very good shearography results. With these promising results the next step was to try to get an opportunity to test the technology on RSRM hardware.

RSRM TESTING

At the same time that ATK was beginning to investigate the use of laser shearography to evaluate TPS un-bonds, a RSRM was returned from KSC (Kennedy Space Center) for evaluation and test firing. ATK used this opportunity to determine if the laser shearography equipment could produce adequate results on a RSRM. A contract was issued to LTI to bring in shearography equipment and level III personnel to perform the inspection of the RSRM.

Prior to inspection on the motor, verification test samples with known flaws as seen in figure 3 were inspected to verify the technique set up is working properly. The test results were compared to test results that LTI had at their factory using a vacuum chamber. A vacuum of roughly 1 psi was more than sufficient to indicate the presence of voids or un-bonds in the test panels and on the RSRM motor.

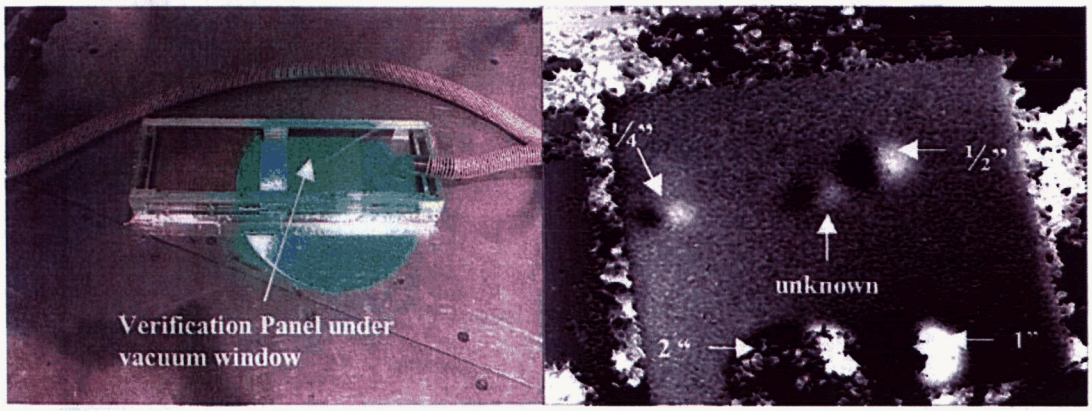

Figure 3 ¼" Cork Verification Panel

The cork and RT455 were inspected in 12 inch long by 6 inch wide sections. After each section was inspected, the vacuum window would be moved to the next section. During the inspection there was always about a 2 inch overlap to ensure all the cork and RT455 was inspected. Each area of the TPS configuration on both sides of the systems tunnel was evaluated using the shearography system. Figure 4 shows location and configuration of the cork and RT455.

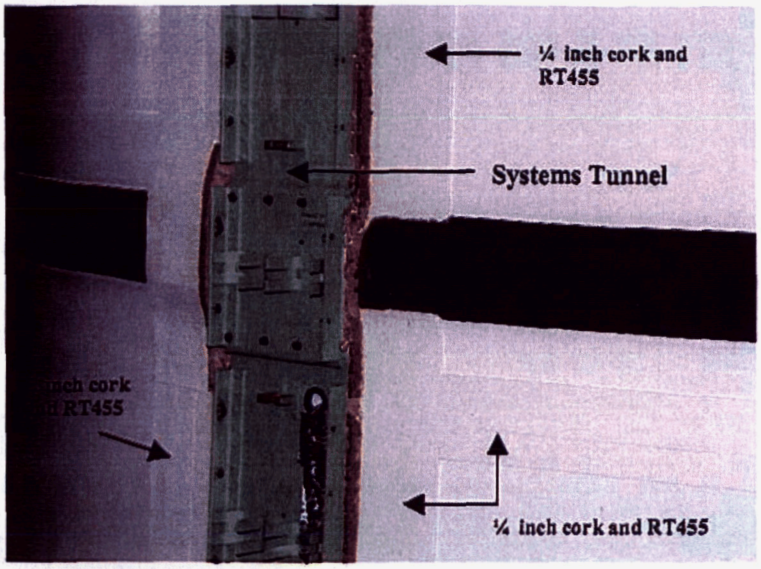

Figure 4 RSRM hardware configuration

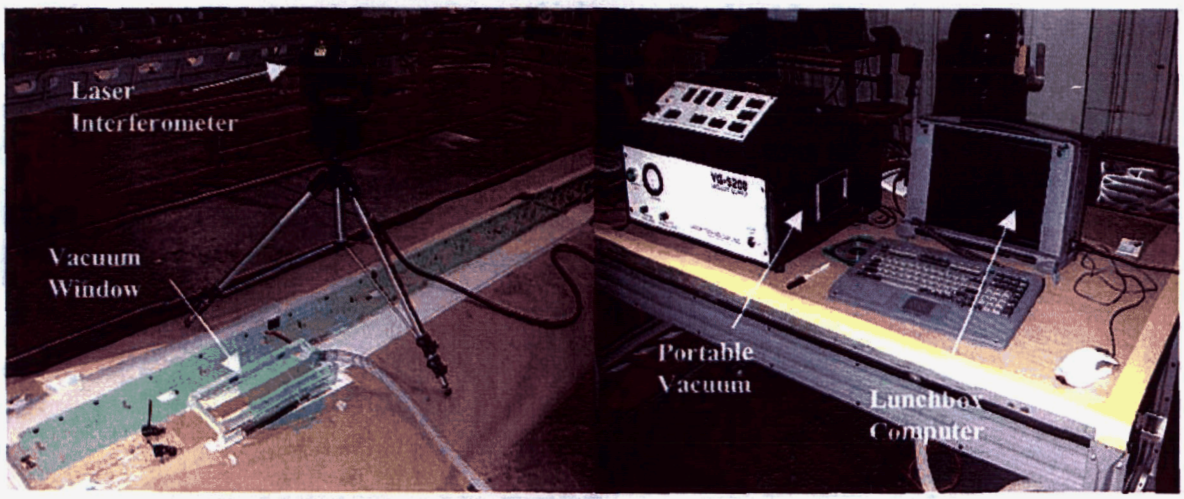

Figure 5 Shearography test equipment

The shearography NDT equipment consists of a tripod with the laser interferometer, lunchbox computer, portable vacuum and a vacuum window that would be placed over the area to be inspected, figure 5. The vacuum window was built using plexiglass and sealed using a combination of tape, neoprene, and plastic sheet. Sealing it to the cork was time-consuming and often required as much as two to three minutes per inspection point once the system was established. A custom designed vacuum window matching to configuration of the cork for each configuration would have greatly lessened the time required.

RSRM TEST RESULTS

As was mentioned, setup and sealing of the vacuum windows was time consuming, but still successful in that the vacuum and windows easily allowed enough applied stress to produce un-bond indications with the interferometer. Moving the tripod and interferometer after each test section also proved to be difficult, but was manageable for this test. The test revealed the need for further tooling for vacuum windows and some sort of an inspection cart to hold the interferometer and to move it along the RSRM case. An indication was identified in ¼" thick TPS cork that was later dissected to verify that an un-bond existed between adhesive coated cork and adhesive coated case paint, figure 6. Other indications were identified in

the ¼" cork, but there was no opportunity to dissect them to verify if the indications were un-bonds, figure 7. No indications were identified in the 1" TPS cork or the GEI cork but the location of the heater and power cables under the RT455 and all of the cork splices and cork pull test plugs were clearly identified, figure 8.

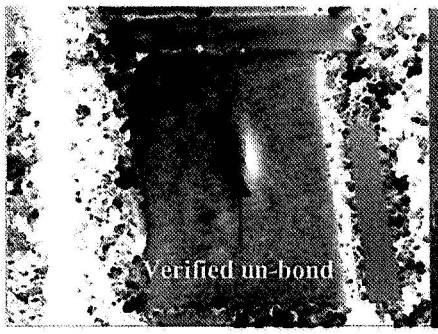

Figure 6
Verified
Un-bond

Figure 7
Unverified
Indications

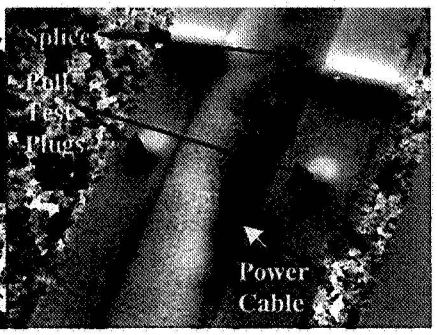

Figure 8
Pull Test Plugs
Power Cable
Cork Splice
Indications

Conclusion

In this paper it has been shown that laser shearography is an effective technique and can be adapted for use on a RSRM for inspection of TPS configurations. Testing to date has revealed that more tests are needed to determine the capability of detection and more equipment development is needed for implementation into the RSRM production flow.

Future Projects

The testing provided ATK with enough confidence in the technology to proceed with the purchase of a Laser Shearography system. The system will have a vacuum chamber that will be used for technique development and characterization studies. The system will also include a custom inspection cart that will be designed to allow for maneuverability of the interferometer during inspections of the RSRM. Several custom vacuum windows have been specified in the system that will fit each configuration of the TPS. The vacuum windows will allow for quick sealing and vacuum loading to alleviate the problems incurred during this testing.

The testing has shown that Laser Shearography can detect voids or un-bonds in cork and RT455, but does not answer how big and under how thick of a material. The test also exposes the fact that creating un-bonds of a controlled size is a problem that must be overcome. Further work is planned to learn how to make controlled size and shape of un-bonds and voids in both cork and RT455. After methods for creating the defects are perfected, samples will be built for the characterization studies. A total of four different characterization studies will need to be performed. Minimum flaw size detection of ¼ " and 1 " cork and ¼ " and 1 " RT455 will all have to be identified.

ATK

An advanced weapon and space systems company

Laser Shearography Inspection of TPS (Thermal Protection System) Cork on RSRM (Reusable Solid Rocket Motors)

John Newman Laser Technology Inc.

Jim Plaia ATK

Mike Lingbloom ATK

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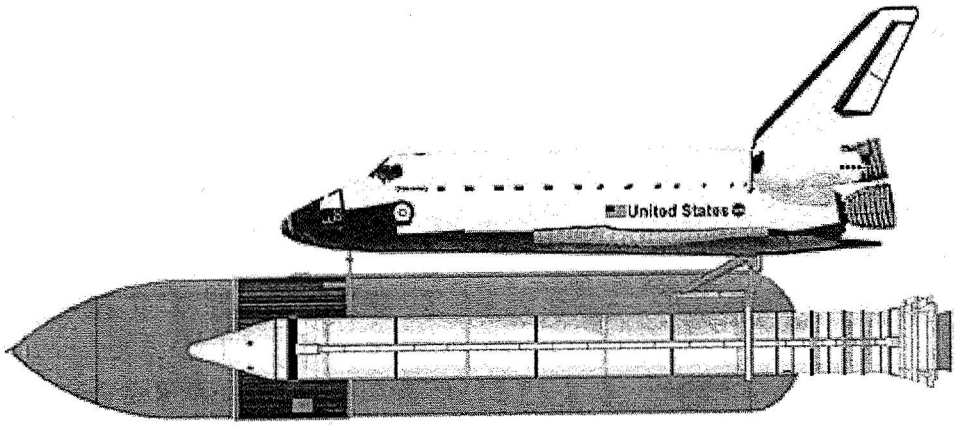
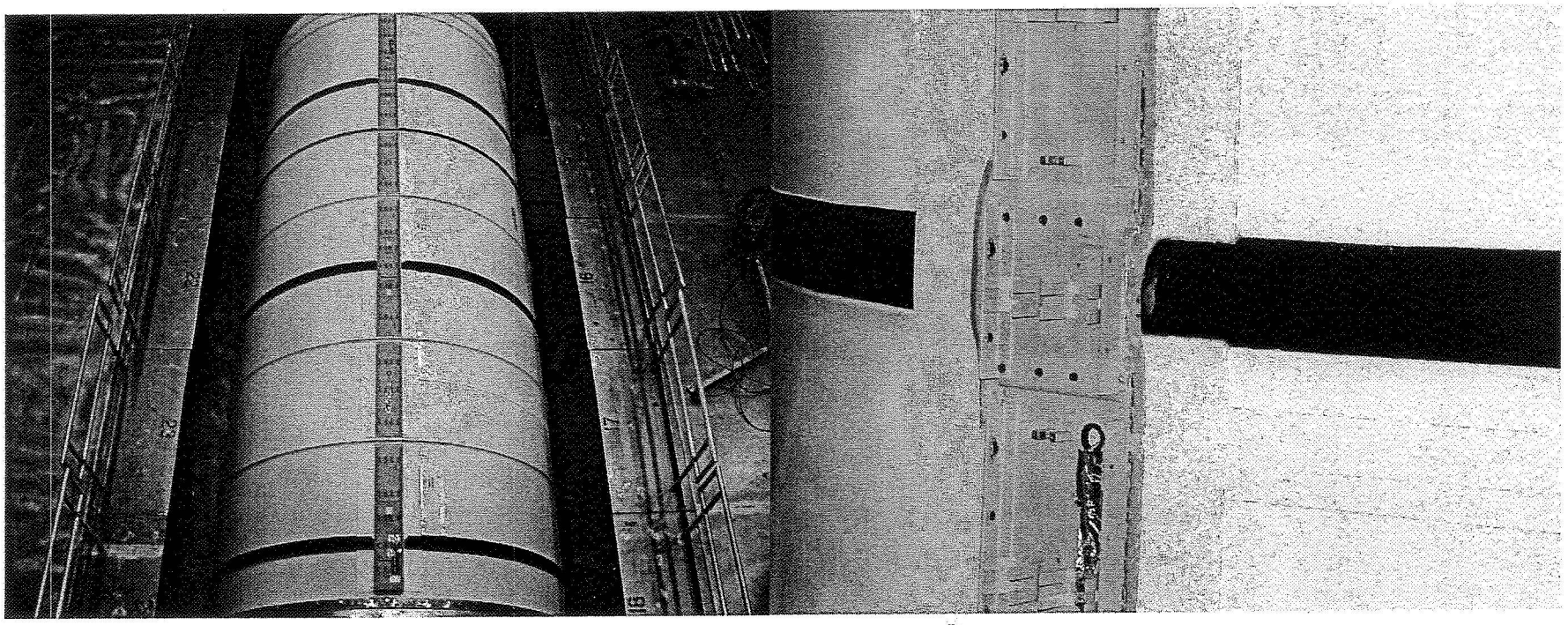
Cork on RSRM



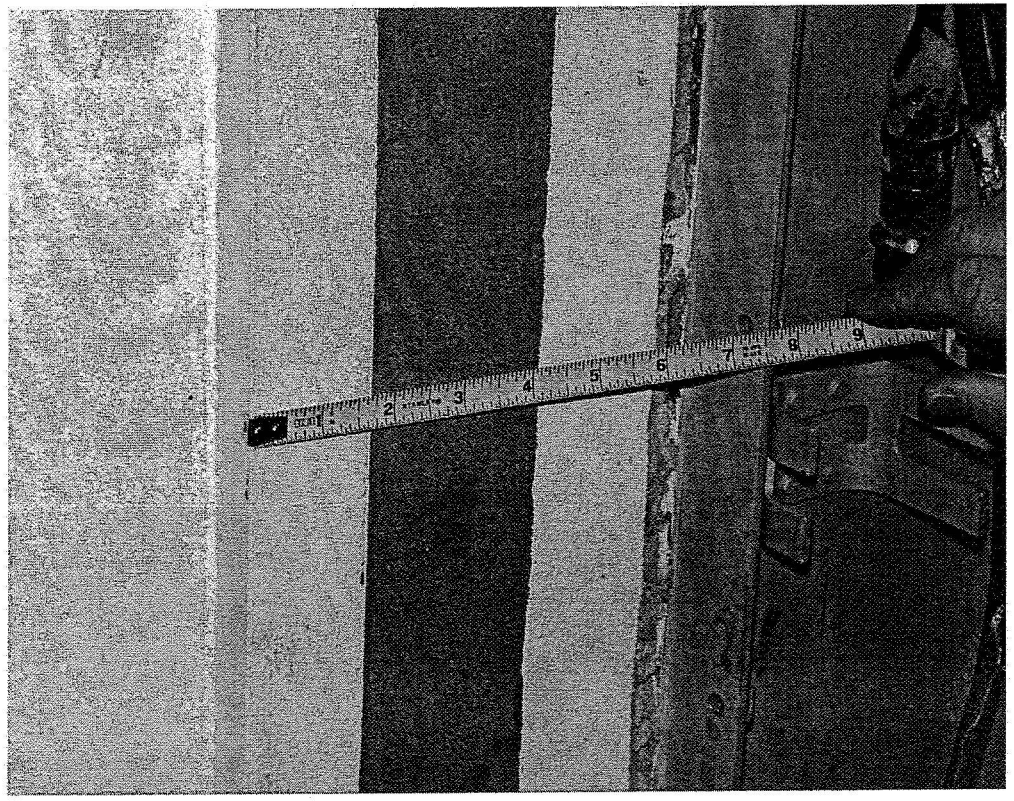
Columbia disaster elevated concern over external bonds on RSRM segments

- Laser Shearography Inspection of TPS (Thermal Protection System)
- Cork on RSRM (reusable solid rocket motors)



Laser Shearography Inspection of
Thermal Protection System,
Cork on RSRM (reusable solid rocket motors)

Columbia disaster elevated concern over external bonds on RSRM segments



Shearography has been selected as the NDT method to inspect the RSRM TPS

- Inspection method is sensitive enough to detect voids and un-bonds at sizes close to existing engineering acceptance criteria
- Inspection method is fast
- Inspection method is safe
- Method provides permanent record of inspection results

Shearography detects sub-surface defects and anomalies by observing changes in the surface of the test part resulting in applied stress

Thermal

Microwave **Vacuum**

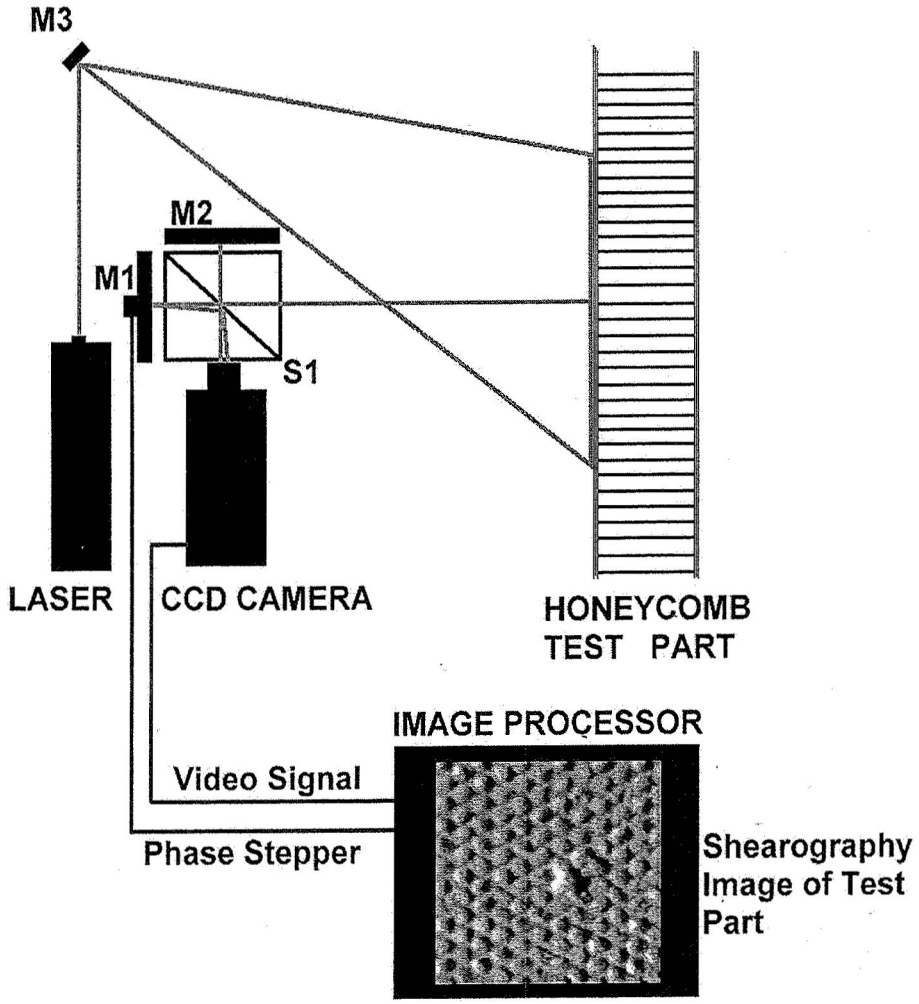
Vibration Excitation

Acoustic

Pressurization

Mechanical Loading

Shearography Inspection of TPS



Michelson lens laterally shears the object beam and reference beam

Monochromatic, coherent light (laser) is allowed to interfere on the image plane

The interference will create light and dark areas due to constructive and destructive interference

Images are recorded in the processor

Stressed images and unstressed images are processed

The defects are revealed in the form of fringes, and are processed into a 3d type of image

Other methods considered

Laser Shearography Inspection of
TPS (Thermal Protection SysteUltrasonicRSRM (reusable solid rocket motors)

Ultrasonic

Automated Tap Testers

X-ray Back Scatter

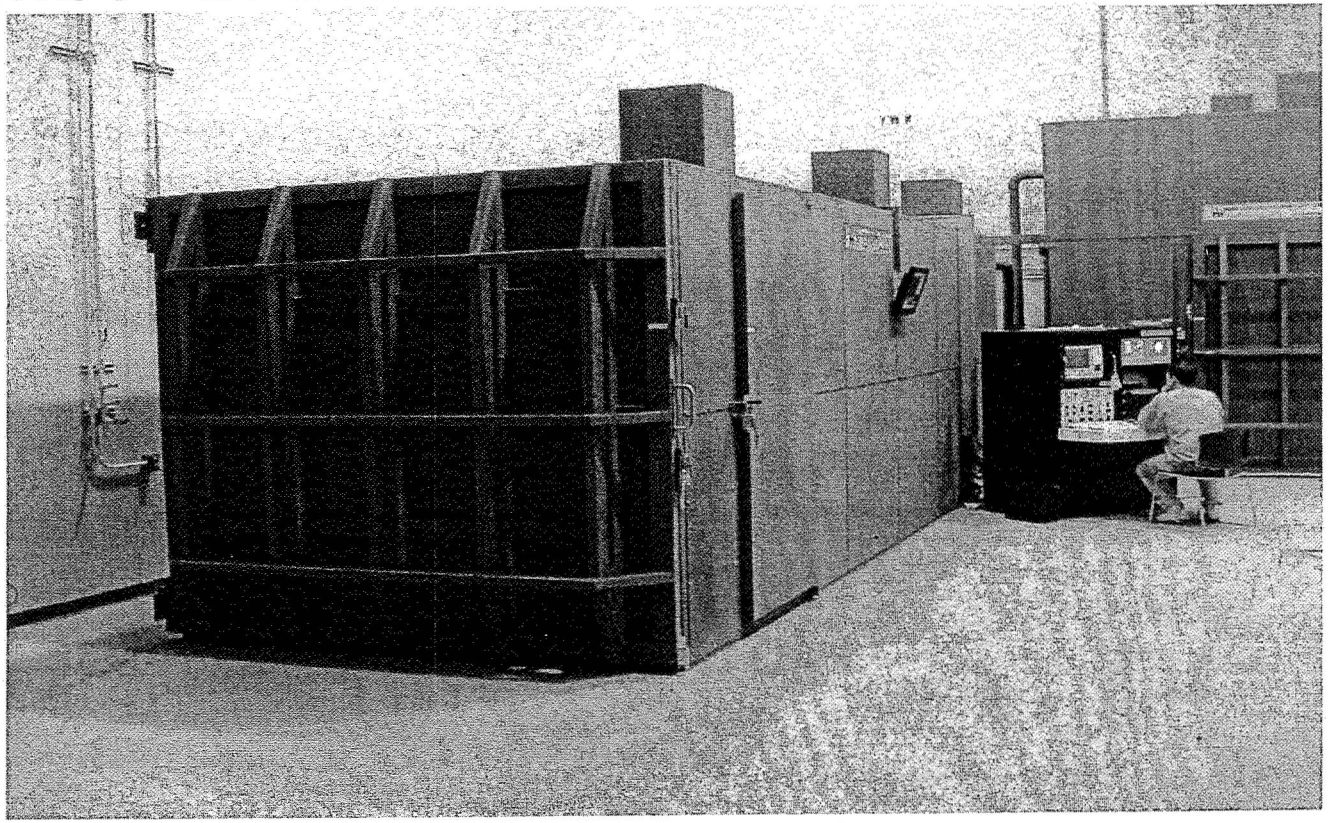
Acoustic Emission

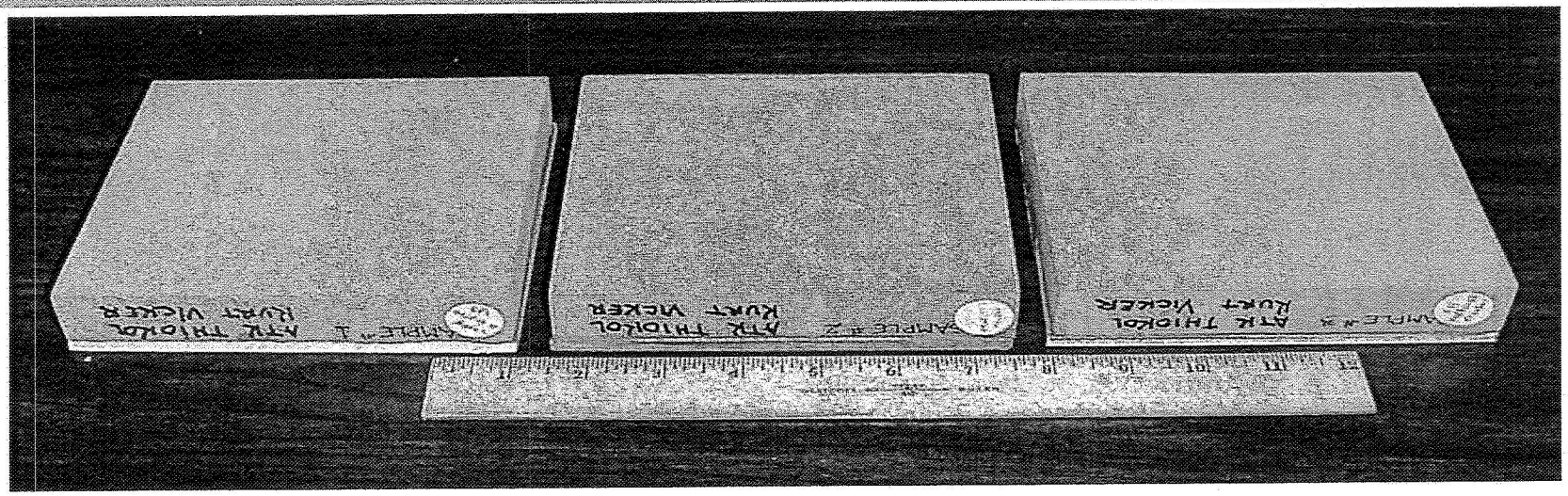
Infra-red Thermography

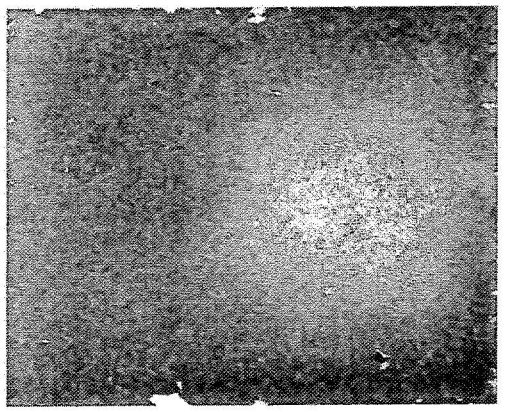
Terahertz Imaging

Several samples were built and were tested with shearography system in a vacuum chamber at LTI

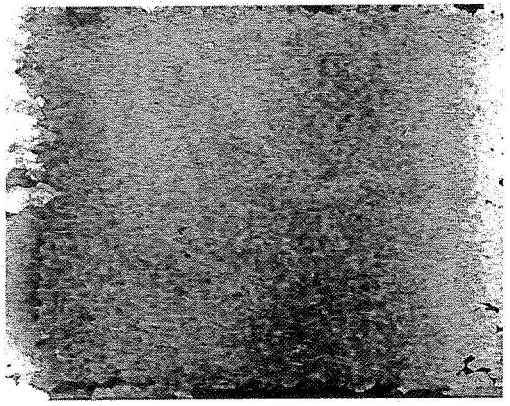
- Laser Separation Nut Protective Cover
- TPS (Thermal Protection System)
- Cork on RSRM (Reusable Solid rocket motors)



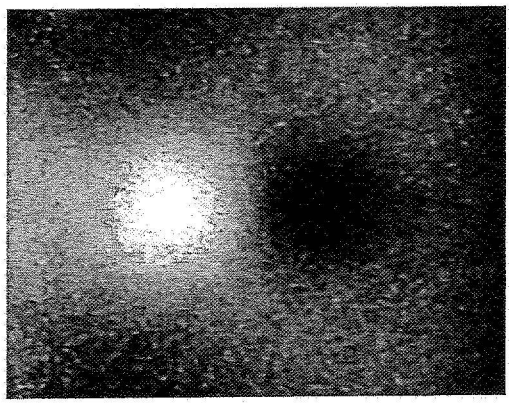




1“ planned void



½” planned void



2“ planned void

- Voids were sized using sizing feature in the software
  - All the voids were ½ inch smaller than planned with the ½ inch void showing no indication
- Samples were inspected with UT from the steel side
  - Voids were sized with UT- all sizes were ½ inch smaller than planned with the ½ inch void showing no indication

Laser Shearography Inspection of TPS (Thermal Protection System) Cork on RSRM (reusable solid rocket motors)

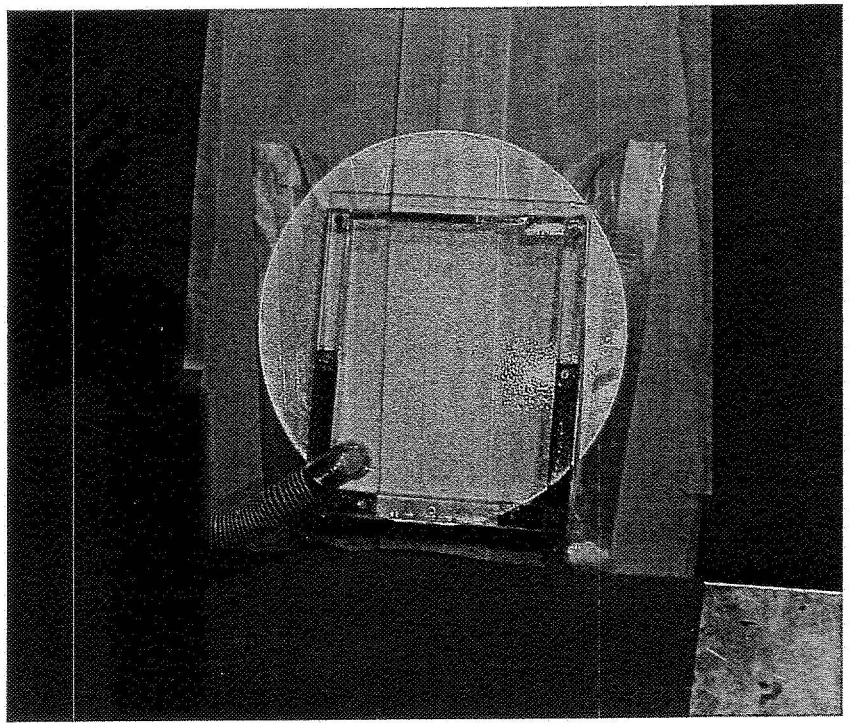
Next step was to test feasibility of inspection of the TPS on full scale hardware

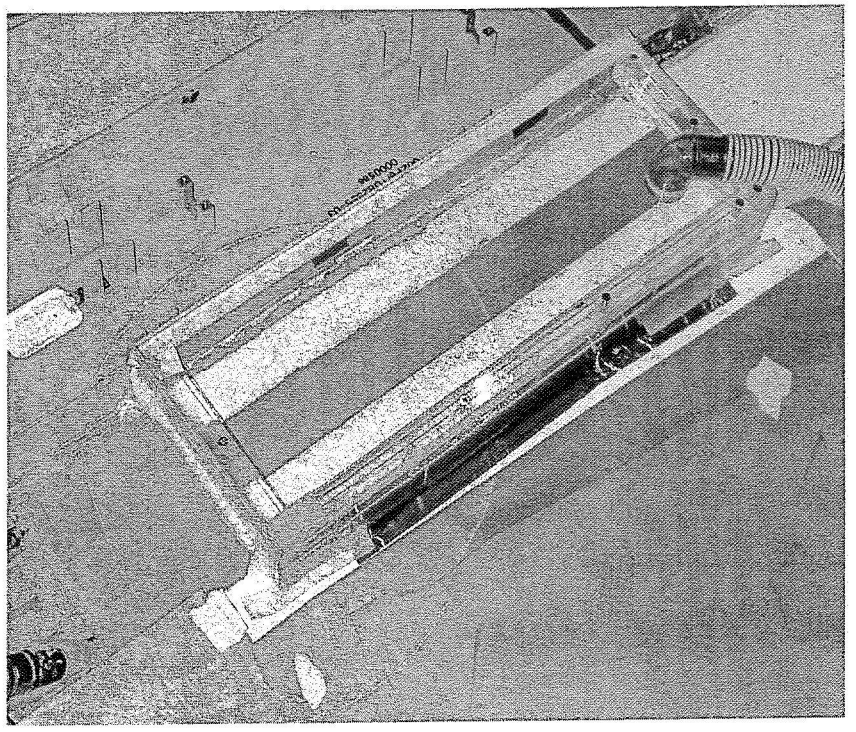
A flight motor was returned from KSC to be used as a test motor

Test plan was approved to use the motor to evaluate shearography

Laser Technology Inc. was contracted to bring in shearography equipment and perform testing

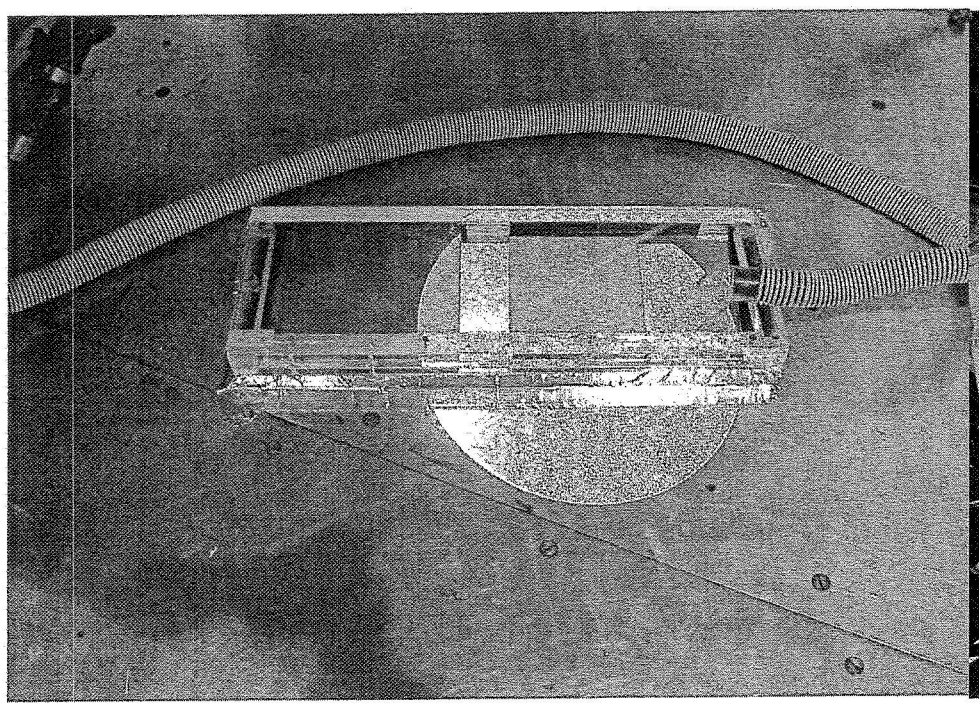
- Vacuum stressing technique worked best on test panels
  - Laser Shearography Inspection of TPS (Thermal Protection System)
  - Cork on RSRM (reusable solid rocket motors)
- Vacuum windows were developed to fit cork and RT455 runs





- Laser Shearography Inspection of
  - TPS (Thermal Protection System)
  - Carbon-Carbon RSRM (reusable solid rocket motors)

Inspection starts with a verification that technique is working properly



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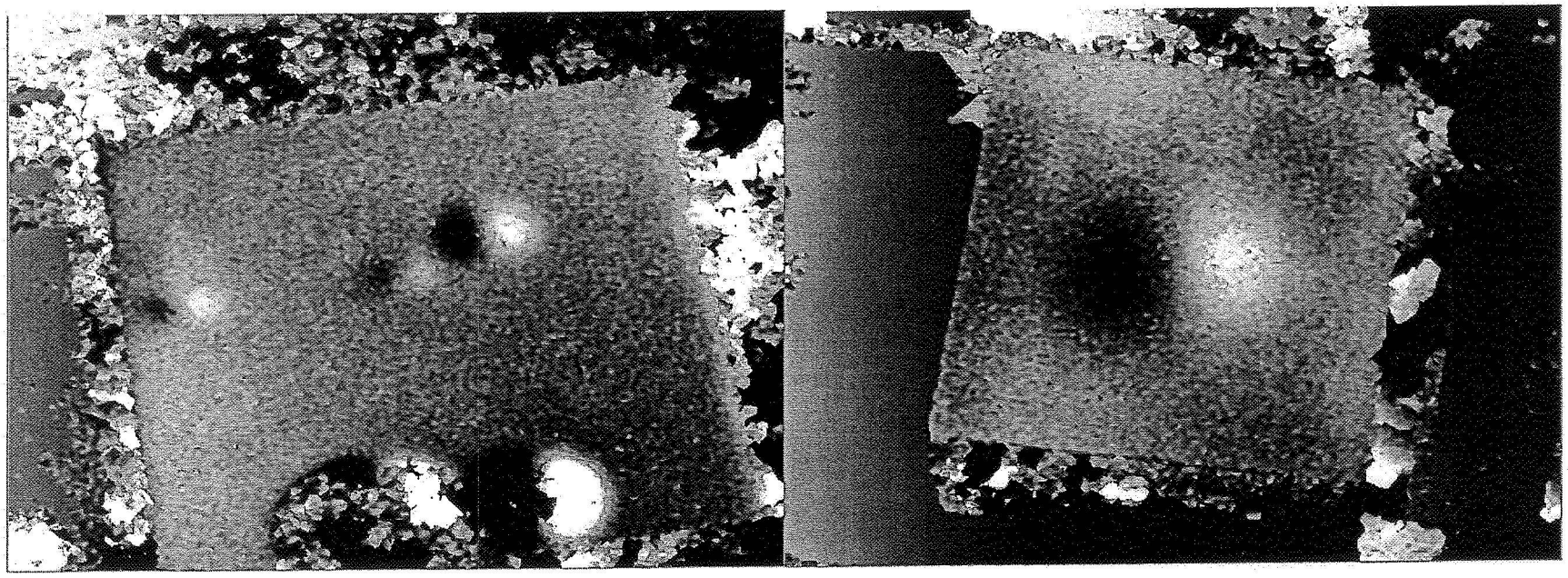
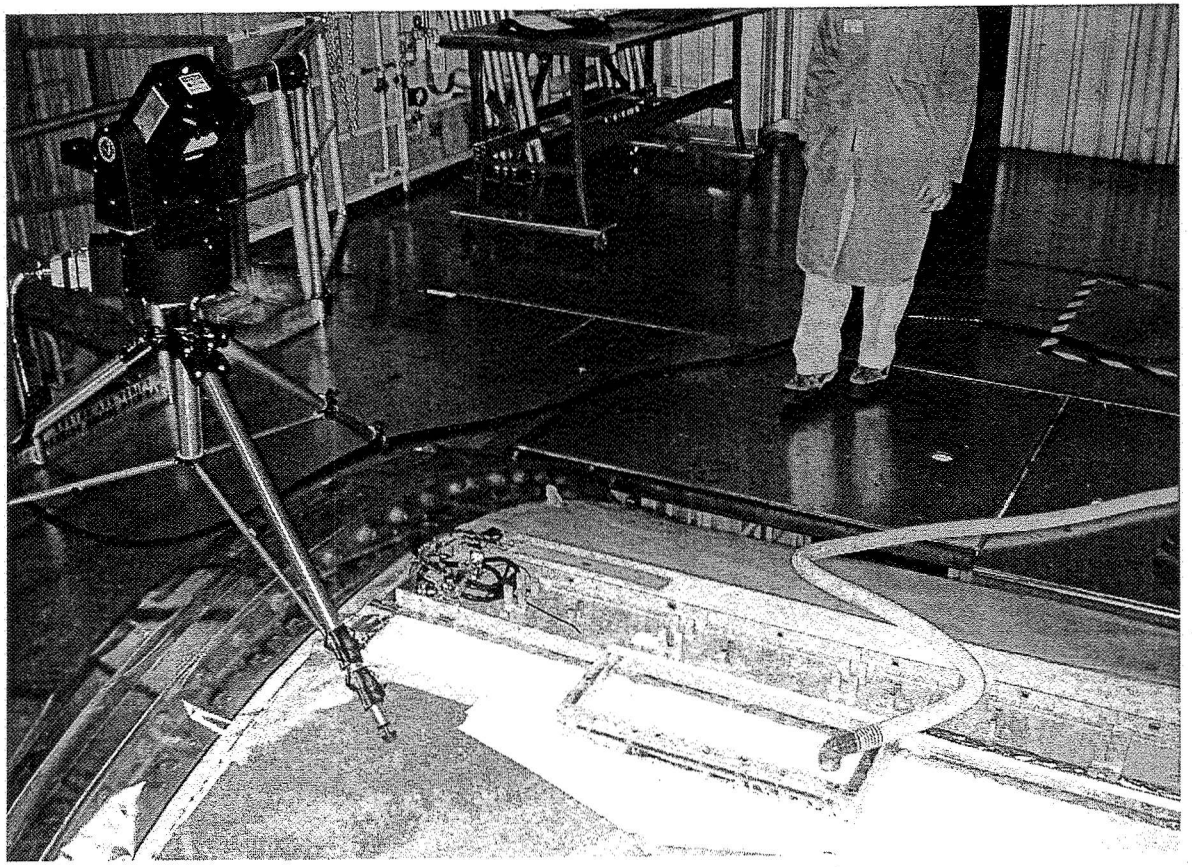


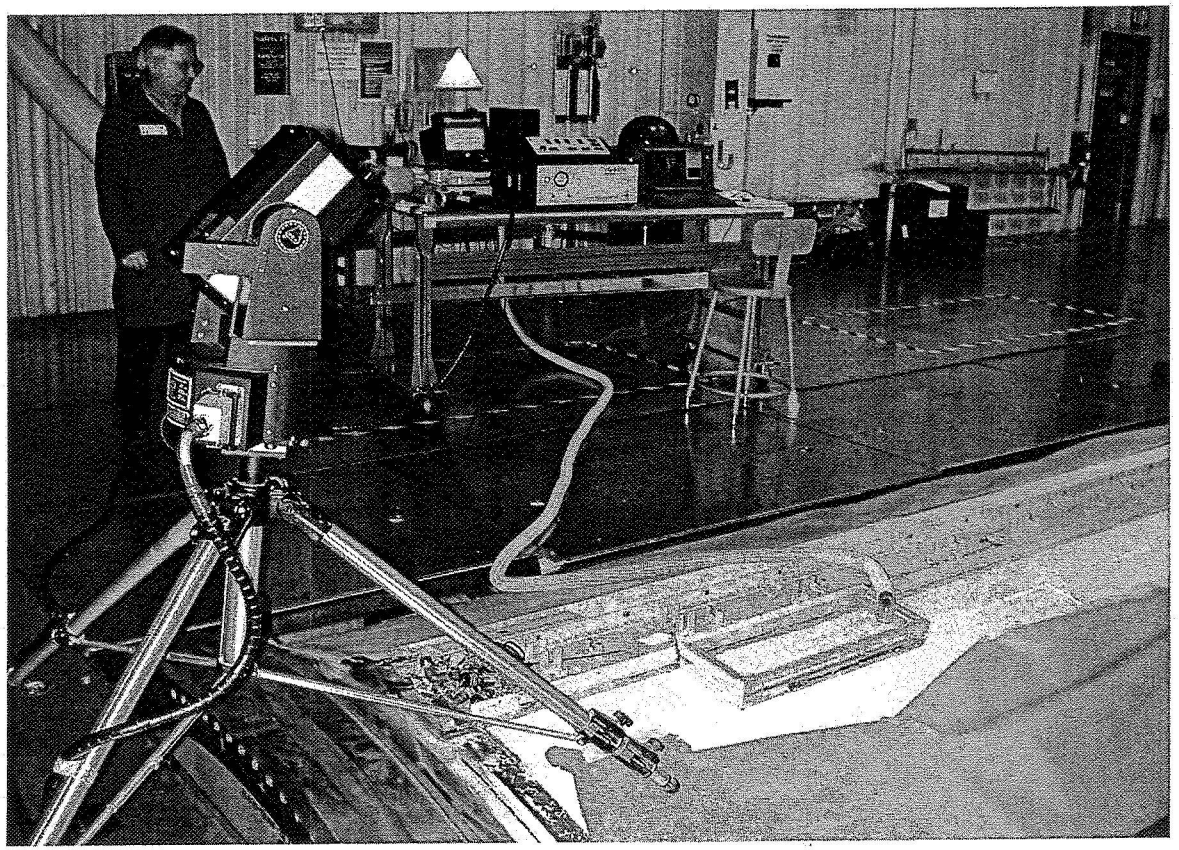
Laser Shearography Inspection of
TPS (Thermal Protection System)
Cork on RSRM (reusable solid rocket motors)

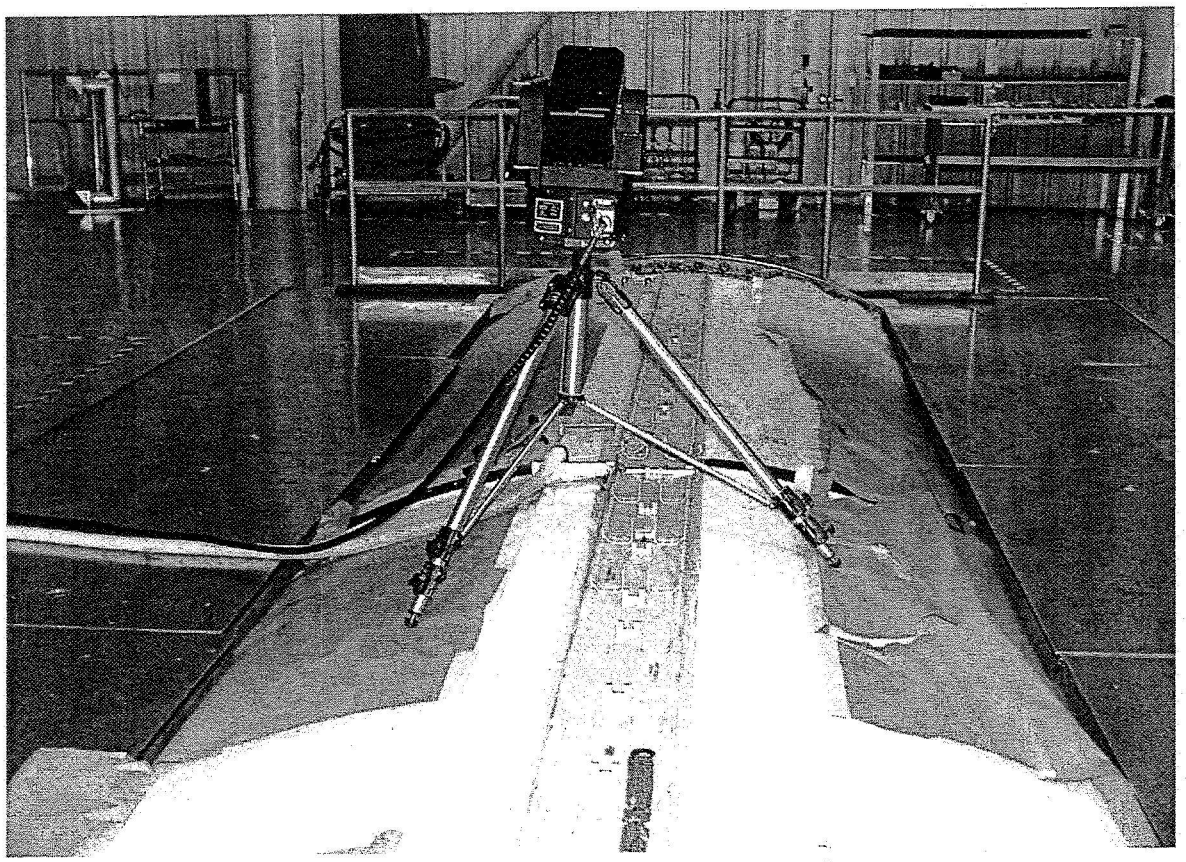
Process required locating the vacuum window over each section to be inspected

Unstressed reference image stored in the processor

Vacuum pressure change of 1 to 2 PSI causes enough stress to the part to get movement of defect areas



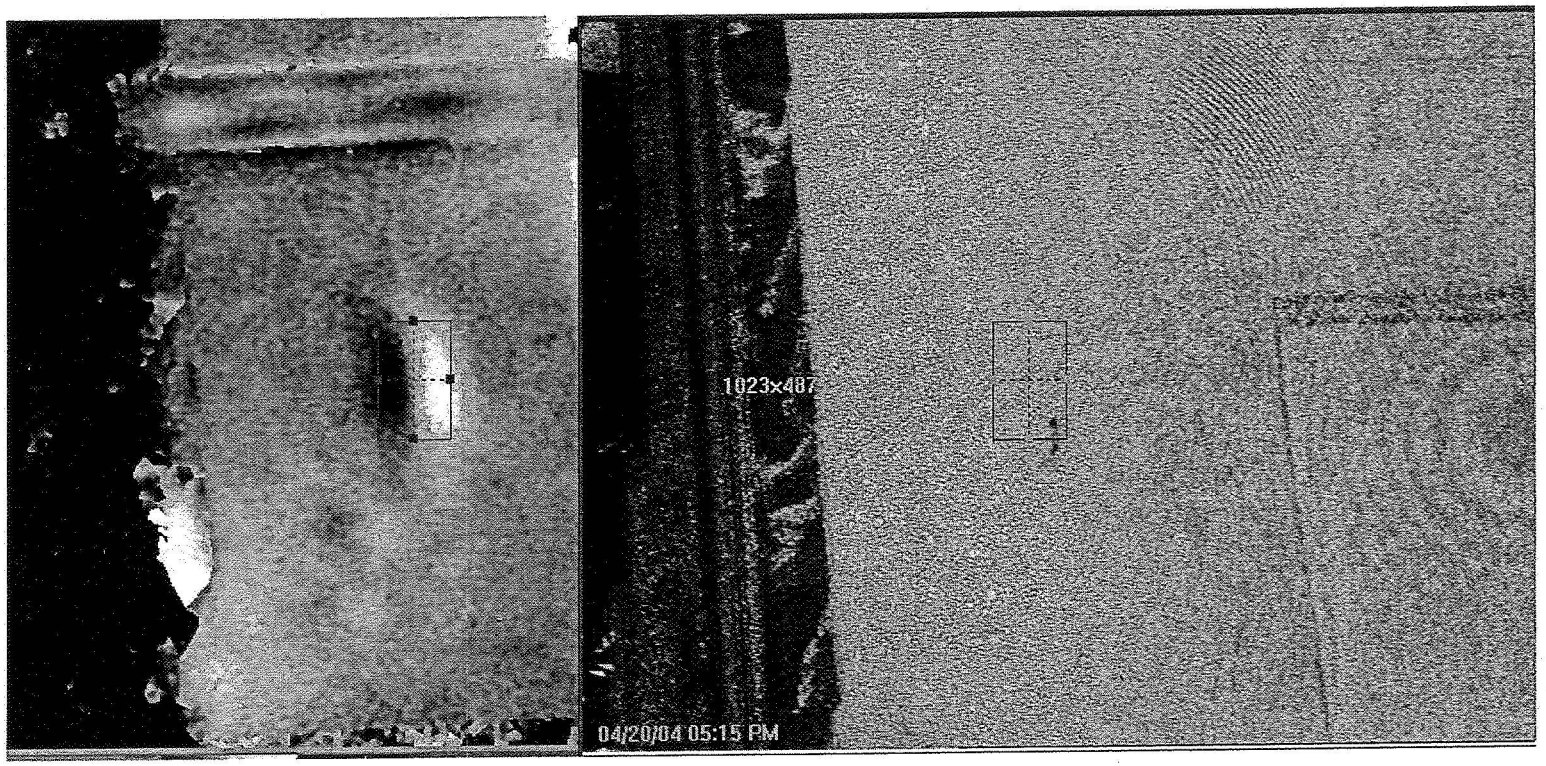




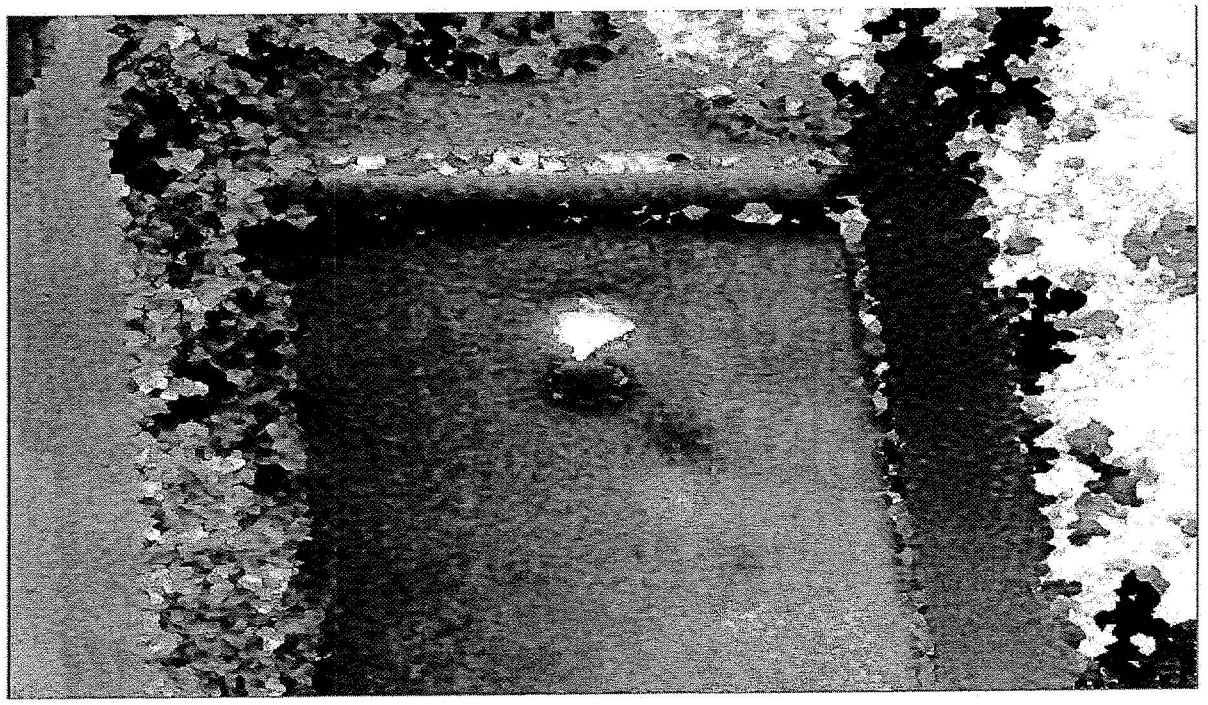
Laser Shearography Inspection of TPS (Thermal Protection System)

Cork on RSRM nozzle aft exit cone (metal substrate)

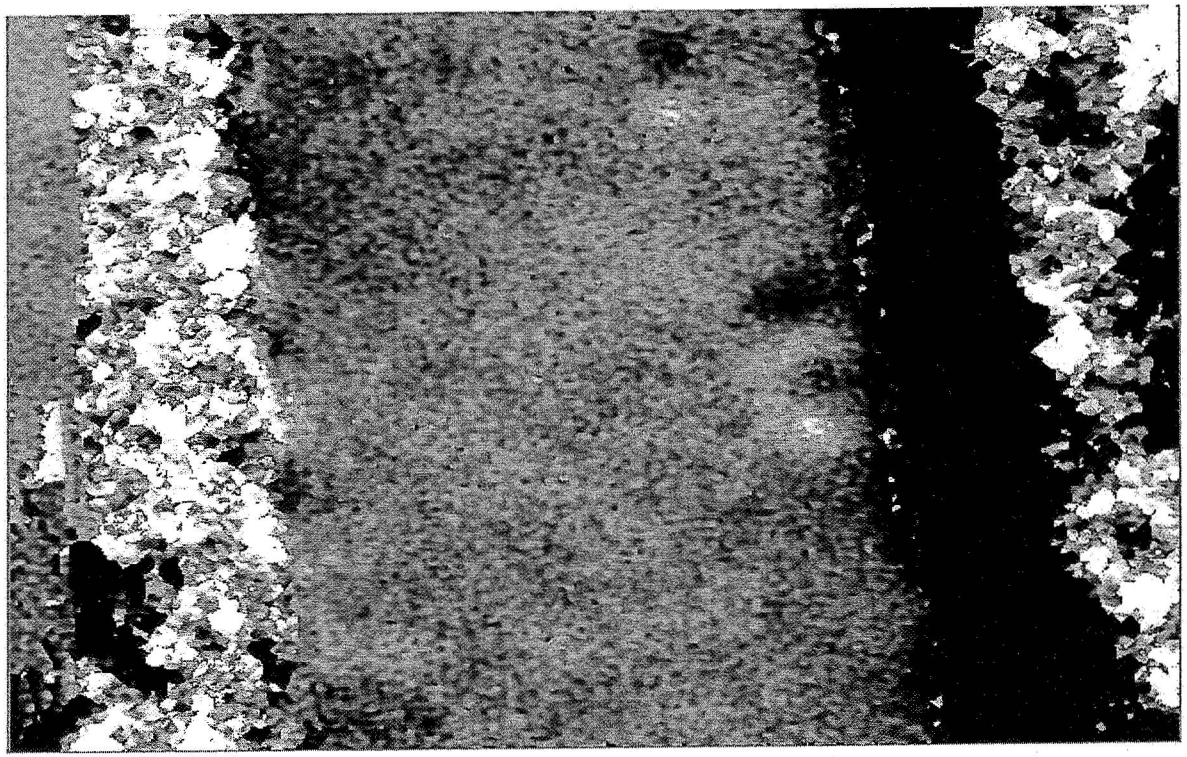
Test results from longitudinal ¼ inch cork runs



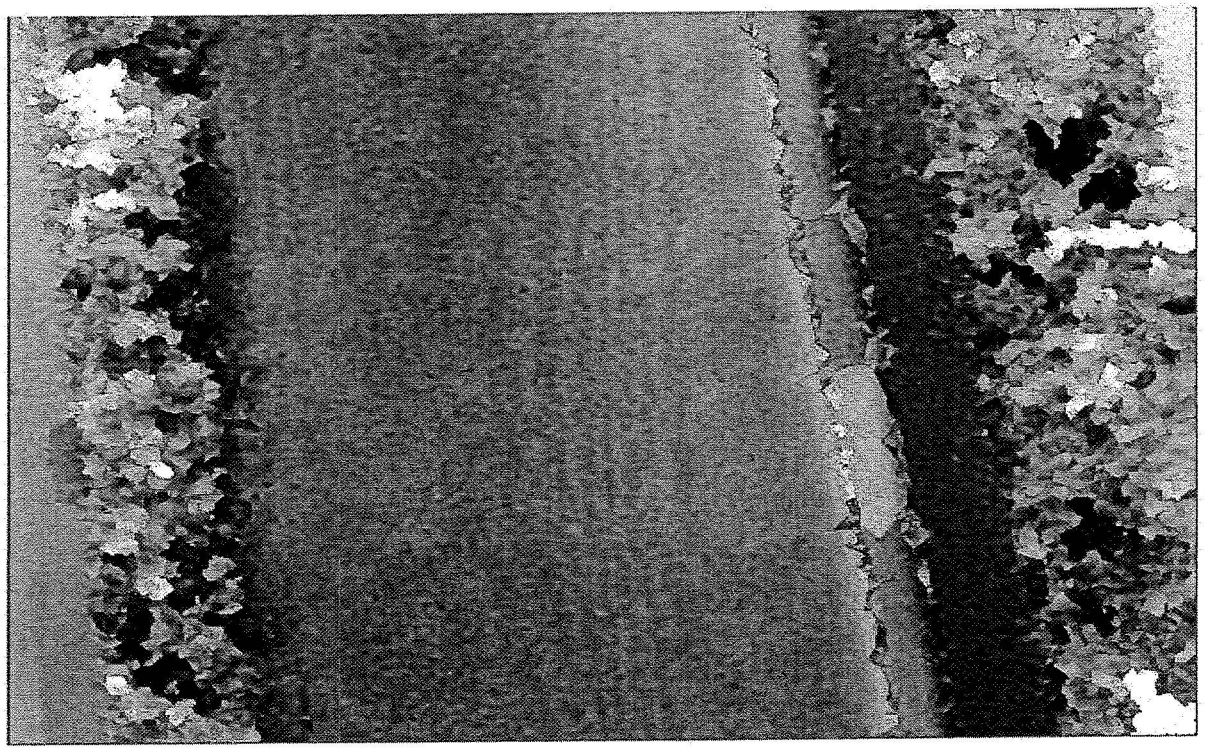
Test results from longitudinal ¼ inch cork runs



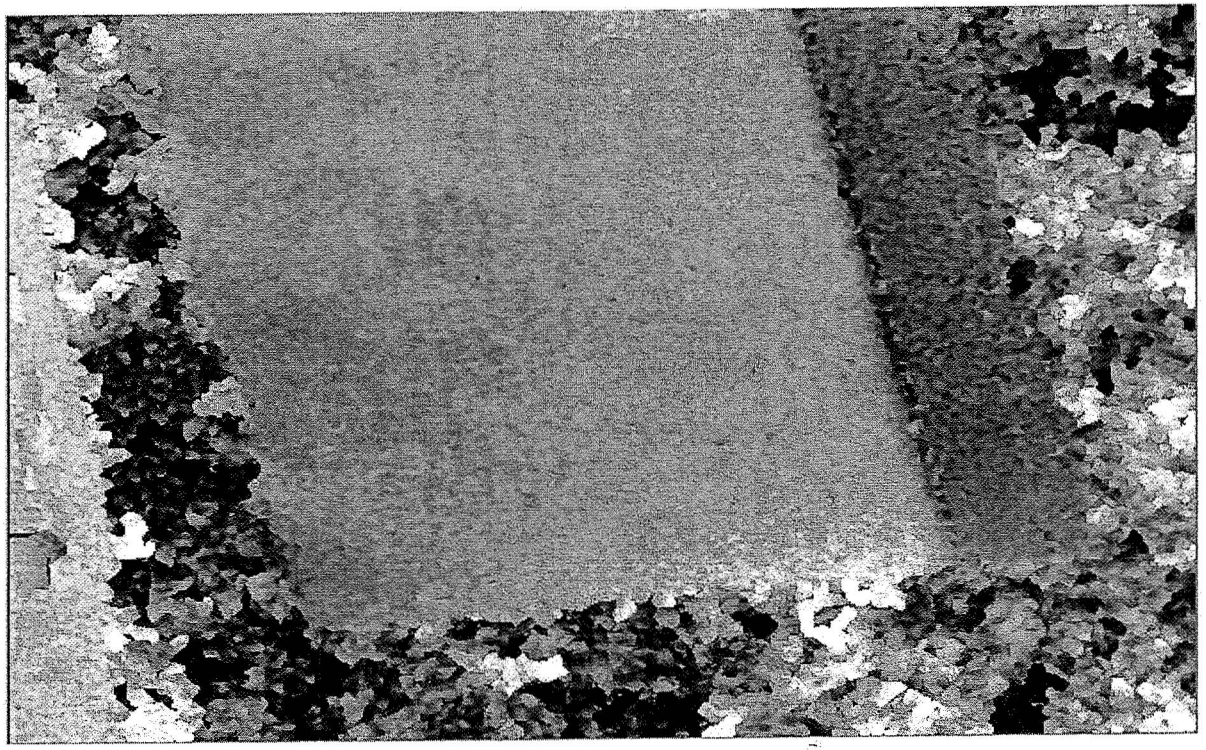
Test results from longitudinal ¼ inch cork runs



Test results from longitudinal ¼ inch cork runs

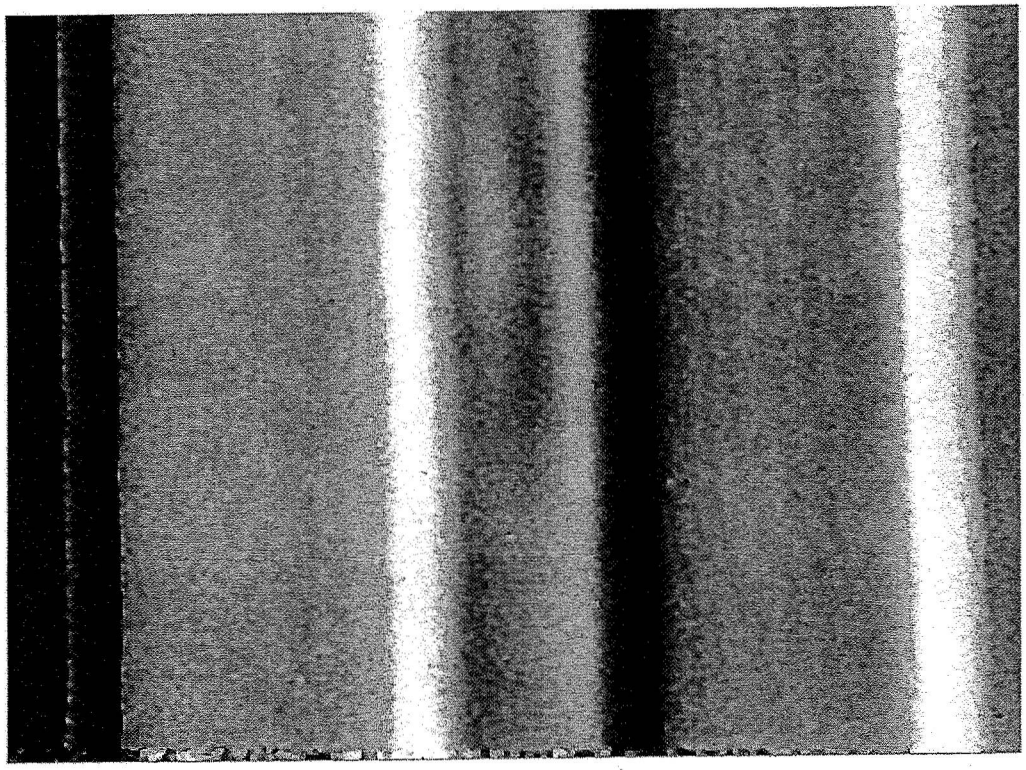


Test results from longitudinal ¼ inch cork runs

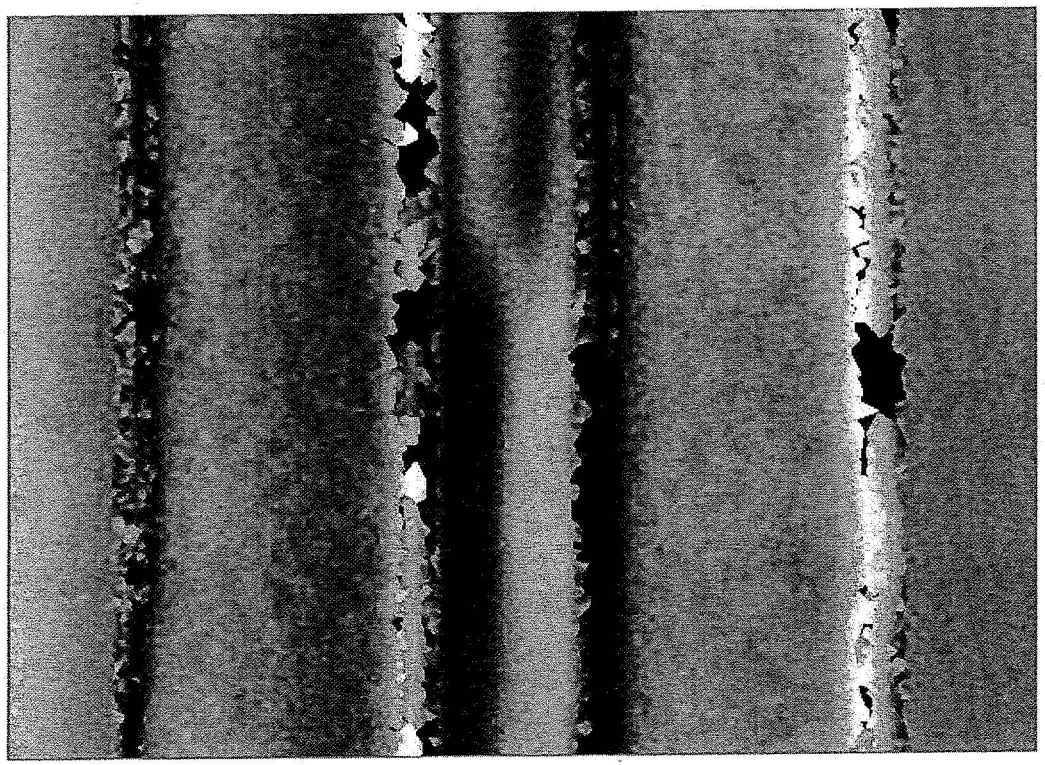


Test results from ¼ inch cork circumferential runs

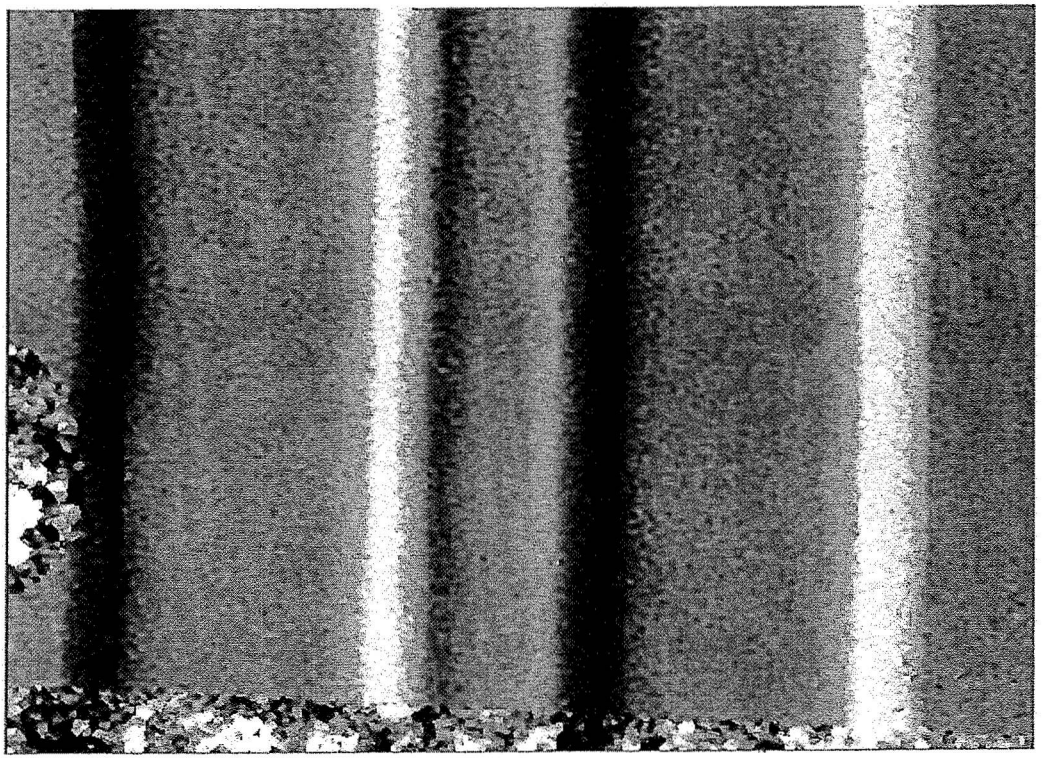
- Laser Shearography Inspection of TPS (Thermal Protection System)
- Cork on RSRM (reusable solid rocket motors)



Test results from ¼ inch cork circumferential runs

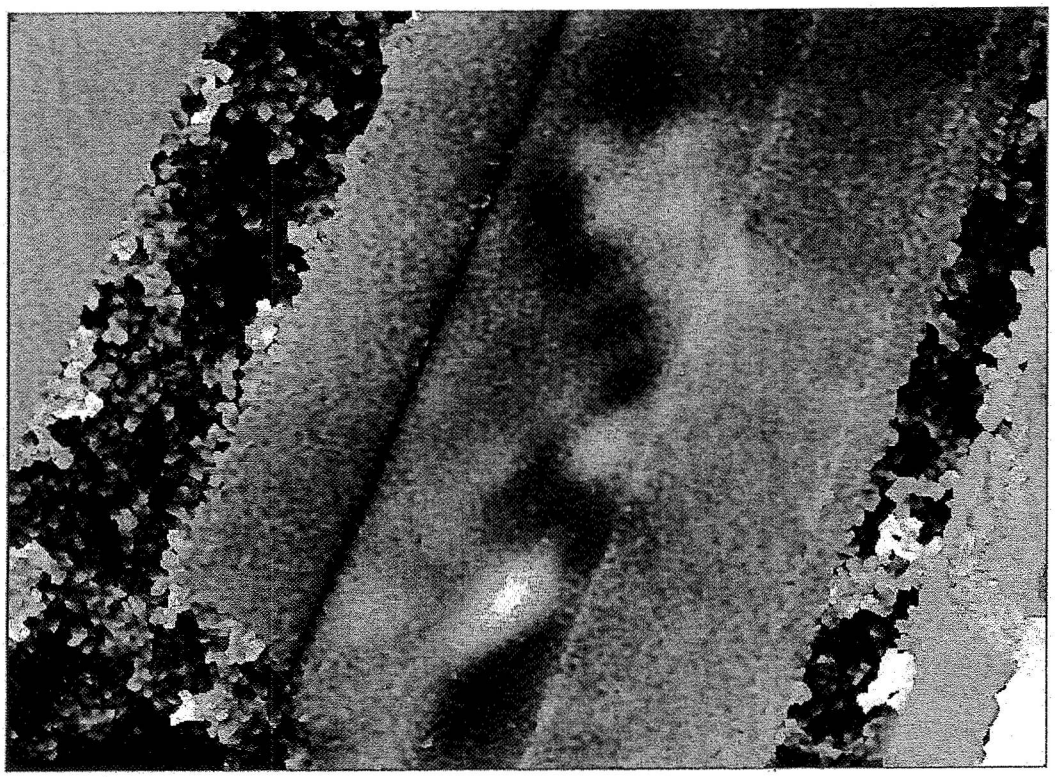


Test results from ¼ inch cork circumferential runs

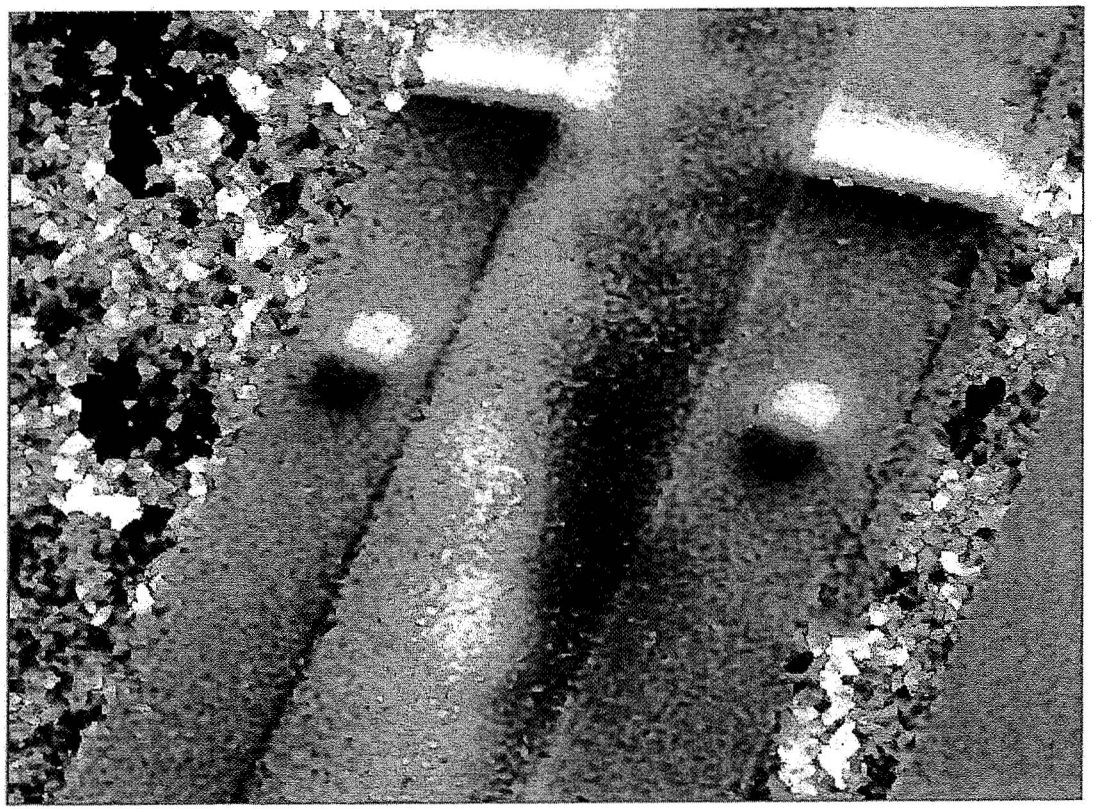


Test results from 1 inch cork and RT455 runs

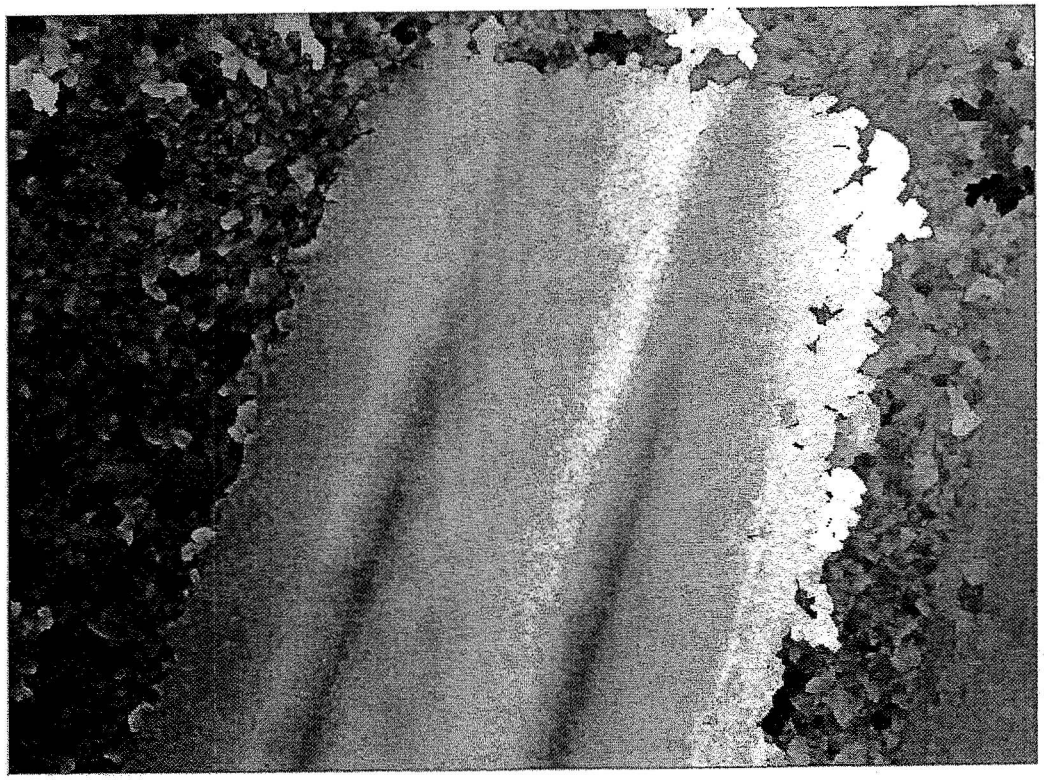
Laser Shearography Inspection of
TPS (Thermal Protection System)
Cork on RSRM (reusable solid rocket motors)



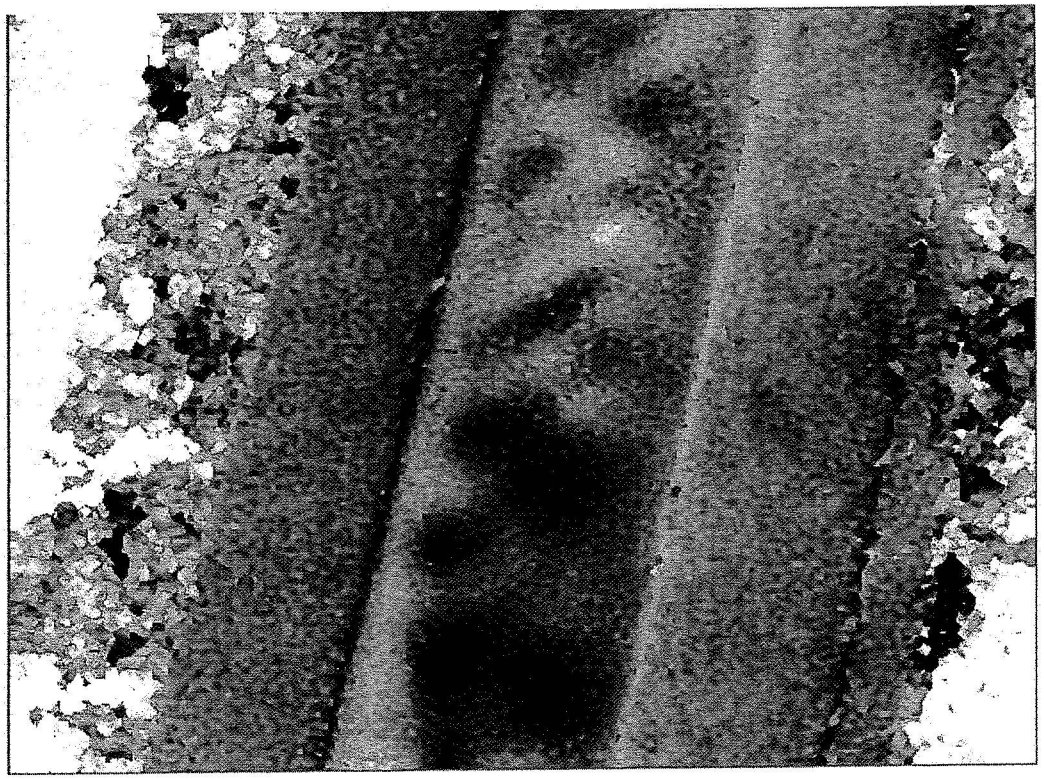
Test results from 1 inch cork and RT455 runs



Test results from 1 inch cork and RT455 runs



Test results from 1 inch cork and RT455 runs



Laser Shearography Inspection of
TPS (Thermal Protection System)
Sorkpon HSRM (reusable solid rocket motors)

Capabilities study in work

1st action is to determine how to make realistic flaws

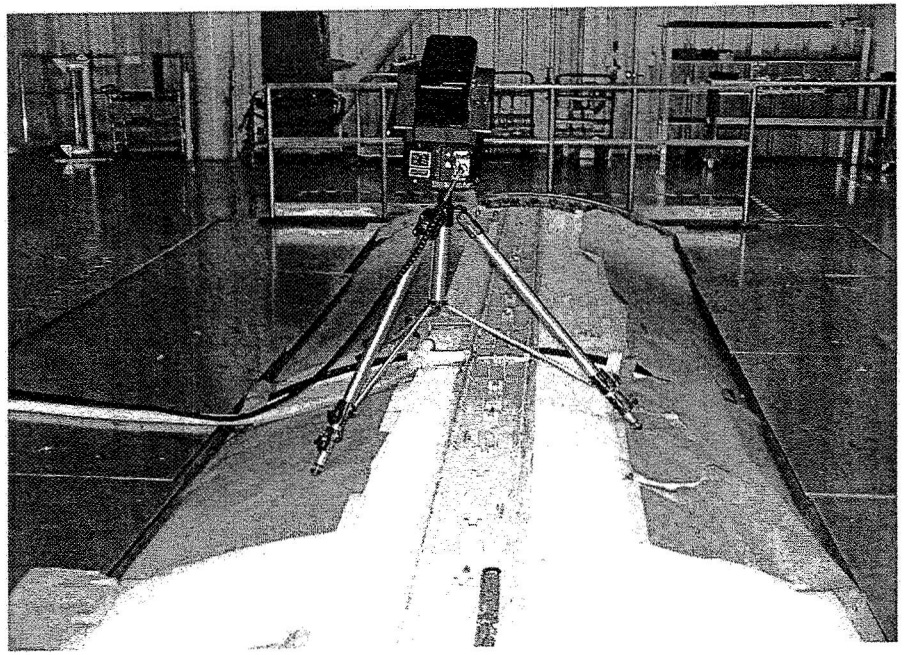
- Samples are being built and dissected to verify reliable techniques for making un-bonds
- Once the un-bond technique is developed a minimum flaw size capabilities study can be performed

ATK has purchased a shearography system

Laser Shearography Inspection of TPS (Thermal Protection System) Cork on RSRM (reusable solid rocket motor)

- 8' X 8' X 8' vacuum chamber for development testing

- custom vacuum windows and inspection cart that will be used to inspect full scale RSRM cork and RT455



Training of personnel to meet NAS-410 requirements

Vendor training as part of system purchase

Testing of 70 cork and RT455 samples that were built for ice impact studies

Testing of 60 cork and RT455 samples that were built for thermal vacuum and hot gas testing

Laser Shearography Inspection of
TPS (Thermal Protection System)
Cork on RSRM (reusable solid rocket motors)

In Conclusion

- Laser Shearography has been demonstrated to be a viable inspection method for TPS materials on full scale RSRM hardware
- Making samples with controlled size of defects will be difficult, but required to perform characterization testing