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**ADVANCED COMPUTED TOMOGRAPHY INSPECTION SYSTEM (ACTIS):  
AN OVERVIEW OF THE TECHNOLOGY AND ITS APPLICATION**

**Lisa H. Hediger**  
**National Aeronautics and Space Administration**  
**Nondestructive Evaluation Branch**  
**Mail Stop EH13**  
**George C. Marshall Space Flight Center**  
**Huntsville, AL 35812**  
**Phone: (205) 544-2544**

**ABSTRACT:**

The Advanced Computed Tomography Inspection System (ACTIS) was developed by the Marshall Space Flight Center (MSFC) to support in-house solid propulsion test programs. ACTIS represents a significant advance in state-of-the-art inspection systems. Its flexibility and superior technical performance have made ACTIS very popular, both within and outside the aerospace community. Through Technology Utilization efforts, ACTIS has been applied to inspection problems in commercial aerospace, lumber, automotive, and nuclear waste disposal industries. ACTIS has even been used to inspect items of historical interest.

ACTIS has consistently produced valuable results, providing information which was unattainable through conventional inspection methods. Although many successes have already been demonstrated, the full potential of ACTIS has not yet been realized. It is currently being applied in the commercial aerospace industry by Boeing Aerospace Company. Smaller systems, based on ACTIS technology are becoming increasingly available. This technology has much to offer the small businesses and industry, especially in identifying design and process problems early in the product development cycle to prevent defects. Several options are available to businesses interested in pursuing this technology.

**BACKGROUND:**

Computed tomography (CT) is a nondestructive inspection method which provides a cross-sectional view of an object using penetrating x-rays. CT images are extremely useful for inspection of complex objects because they provide a visual representation of defects without the scatter and superpositioning problems commonly encountered in conventional x-ray inspection.

In CT, the x-ray beam passes through the object under test and is absorbed to various degrees as it travels through. The nonabsorbed x-rays strike an array of electronic detectors. Each individual detector in the array is discrete. That is, each detector collects the transmitted x-rays along a sharply defined line of sight between it and the x-ray source. As the part location is systematically changed and the x-ray measurements are repeated at each new location, a data set consisting of several million individual line x-rays is compiled. With the help of a fast array-processing computer, this collection of line x-rays from different orientations is mathematically combined to reconstruct an image of the object cross-section at a particular height.

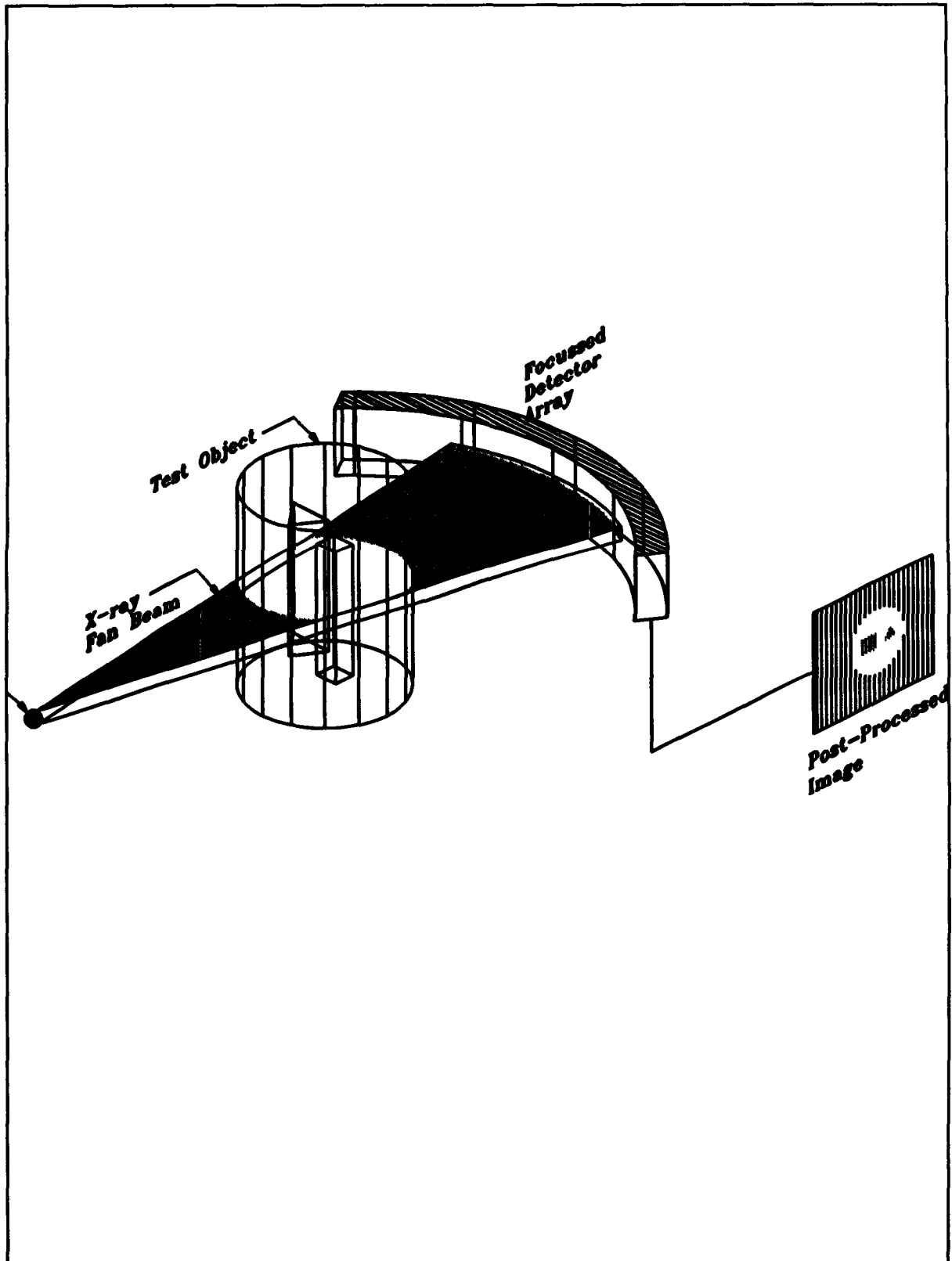


Figure 1: CT uses a highly collimated x-ray fan beam, a linear array of digital detectors, and a fast array-processing computer to produce a cross-sectional image of the object.

Computed Tomography (CT) is becoming popular with researchers in the areas of composite materials and liquid and solid propulsion. CT provides a great deal of information in a digital format, which can be stored on a compact media, recalled quickly, and digitally enhanced to highlight details of interest.

In contrast to other nondestructive evaluation techniques, CT places fewer restrictions on component configuration and material selection. Unfortunately, the design of a CT system is usually optimized for a known type of material or component size, to allow the manufacturer to produce a system which will perform satisfactorily for the required application at minimal cost.

Eight years ago, Marshall Space Flight Center (MSFC) became increasingly involved with composite materials and solid propulsion research. CT was attractive because it provided meaningful quantitative data. In the early days, hospital CT systems were used to evaluate small samples. However, the need to evaluate subscale test and small flight items soon developed. A complete needs and requirements analysis revealed a need to evaluate components ranging from four inches to four feet in diameter and materials ranging from steel to rubber. Available CT systems were not flexible enough to meet these requirements, so the Advanced Computed Tomography Inspection System (ACTIS) was developed as a cooperative effort between MSFC and Bio-Imaging Research (BIR).

Most x-ray CT systems consist of a single x-ray source, a linear array of approximately 125 detectors, an array-processing computer, and peripheral devices. ACTIS system consists of four high-energy x-ray producing devices, an integrated array of 625 solid-state x-ray detectors, a 162 channel data acquisition system, mechanical gantry with 13 degrees of freedom and its control computer, a fast parallel image-processing computer, an integrating operator console, and peripheral devices.

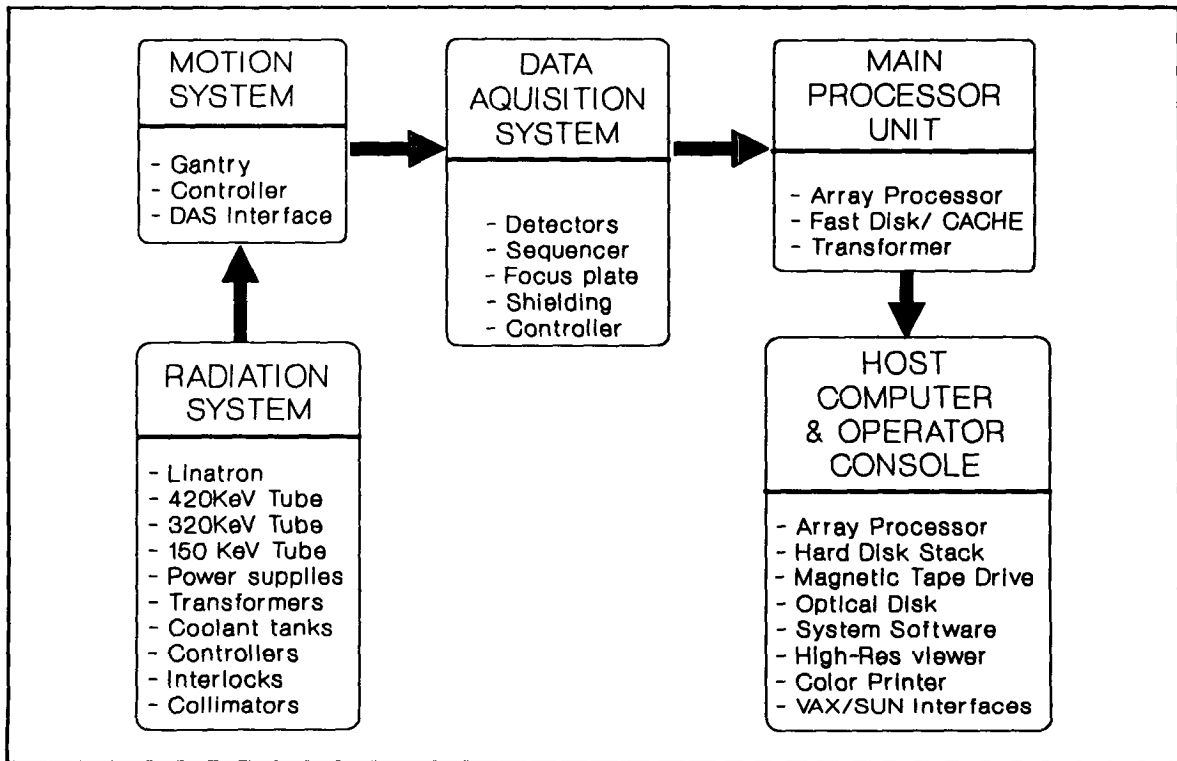
Typically, the performance of a CT system is determined by the following characteristics:

- Suitability for application
- Spatial resolution
- Contrast sensitivity
- Scan speed
- Ease of use/maintenance

Each of these performance characteristics affects cost. ACTIS provides superb technical performance at a competitive price. ACTIS is the most flexible CT system available. Its performance, in terms of spatial resolution, scan speed, and contrast sensitivity are exceptional. Its flexibility and technological merit have made ACTIS one of the most heavily-loaded industrial CT systems in the world.

NASA applies ACTIS to investigate the behavior of new and exotic materials in the ballistic environment. Test motors, incorporating these new materials, are assembled and test-fired at MSFC. Pre- and post-fire CT analysis reveals how the structure of the material is altered by ballistic conditions. ACTIS is sensitive to changes in material density of about 0.05 percent, so it is sensitive to even slight changes in material structure. Typical scan times per slice range from seven minutes to thirty minutes, depending on the object size and opacity, and the required contrast sensitivity, and spatial resolution.

Visualizing defect location is sometimes a problem with CT, since it is difficult for most laymen to think in terms of slices. ACTIS employs Multi-Planar Reconstruction (MPR) as a visualization tool for CT-located defects. In MPR, individual CT slices are digitally stacked and displayed from each of three perpendicular viewing angles. Visualizing defect location with MPR is typically quite easy for



**Figure 2: Simple Block Diagram of ACTIS**

technical personnel, who are used to dealing with engineering drawings.

A number of special image-processing features are available with ACTIS. These features are available from the main control console and from a remote imaging workstation, which is interfaced to the ACTIS host computer. Special features include contrast adjustment, statistical image analysis features, relative density plots along a line through the image, zoom magnification, and shaded surface rendering based on a stacked set of CT images.

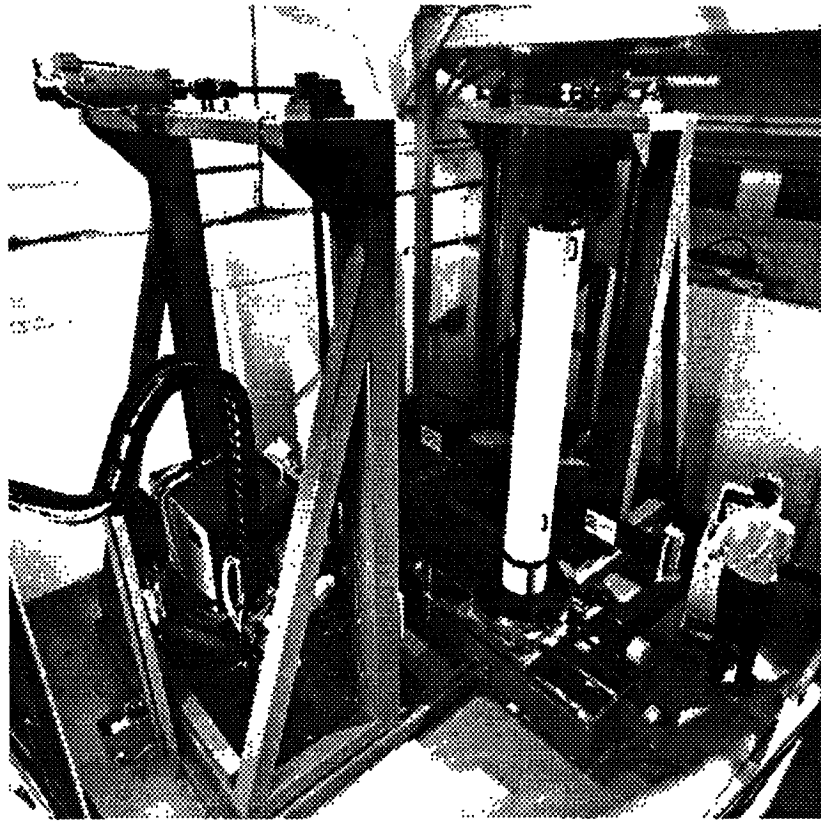
Although the cost of ACTIS is competitive with most large industrial CT scanners, CT in general is an expensive method of inspection due to long scan times, the need for semi-skilled operators, and the acquisition / maintenance cost of the equipment. In fact, CT is so expensive that in most cases, it makes little financial sense to use it for routine inspection. However, during the early stages of new product development, it provides information on design and process weaknesses which can save money in the long run. Recently, ACTIS significantly affected the development of an improved version of the Space Shuttle Main Engine (SSME) Turbopumps by spotting anomalies in the casting process during the early development phase of the program. These defects (slight imperfections in the internal walls) were impossible to detect with conventional inspection methods. Without ACTIS, the program may not have ever known they existed. Further, the program discovered rework of these defects was difficult and costly. As a result of continued CT analysis, minor changes made to the casting process eliminated these costly defects at the source.

In addition to NASA programs, ACTIS has benefitted many military programs. It has been used to inspect thermal batteries for Air Force systems, artillery storage canisters for Army depots, and housings for Navy cruise missiles. Most of these agencies have special-purpose CT systems of their own.

One of the most unique applications of ACTIS was the inspection of a 100-year-old time capsule for *National Geographic* magazine. The time capsule, commemorating the centennial of the inauguration of George Washington, had been sealed in 1889. Before the box was opened, NASA had the opportunity to scan the contents with ACTIS. Originally, ACTIS was intended to identify how the box was assembled, and to offer suggestions on how to open it without damaging the contents. ACTIS far exceeded our expectations, providing not only information about the construction of the box (wood sandwiched between two layers of tin), but details pictures of the contents. When scanning was complete, NASA had tentatively identified five medallions, the letters on a calendar, and several books. Our findings were later verified through image enhancement performed at Technical and Analytic Sciences Corporation.

ACTIS was used to perform feasibility studies for applications of CT in the lumber industry. These studies revealed that CT provides useful information to the lumber mills, allowing them to grade lumber, optimize cutting plans to maximize yield, and cut costs by identifying scrap prior to finishing.

ACTIS has been used by the U. S. Department of Energy to inspect barrels of stored nuclear waste. The system can identify free liquids trapped within the waste and structural flaws in the barrels themselves, two significant hazards in nuclear waste storage. Using ACTIS, scientists are able to identify barrels which present an unacceptable risk, and take preventative action. ACTIS was also used by the DOE to identify the contents of waste barrels. To test these capabilities of ACTIS, the DOE provided a 55-gallon drum of simulated nuclear waste. In the barrel were several common objects: rubber o-rings, a pen, a filament, a comb, a lead-lined rubber glove, and others. ACTIS operated blind. That is, the operators were not told anything at all about the contents of the barrel. The tests produced some impressive results. ACTIS was able to image the face on a dime contained in the 55-gallon drum of waste.



**Figure 3:** ACTIS Mechanical Gantry with 13 degrees of freedom accommodates objects ranging in diameter from 4" to 4' and weighing up to 2000 pounds.

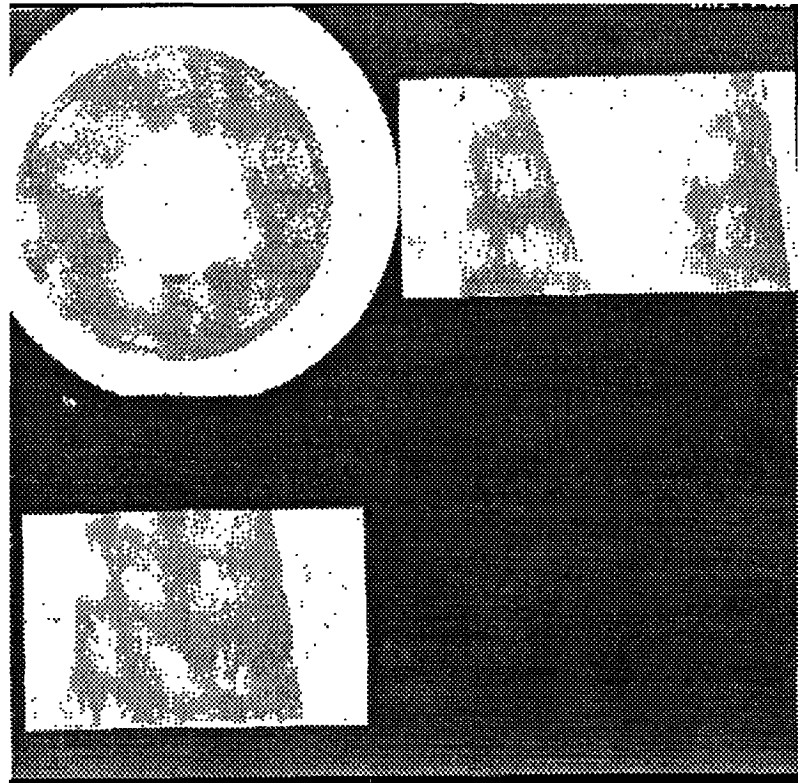
Various automotive manufacturers have explored the use of ACTIS in designing new products. The system has been used to inspect prototype steering wheels, engine blocks, gear boxes, and other structures for automotive applications. ACTIS has become an integral part of prototype development for some of these companies. American automotive manufacturers use CT data to evaluate performance of new designs and processes early in the development cycle to reduce the potential for defects in routine production.

ACTIS systems are now sold as off-the-shelf items. Unfortunately, these systems are too expensive for most small businesses to afford. However, there are several alternatives for small businesses and industries interested in applying ACTIS technology. First, various CT

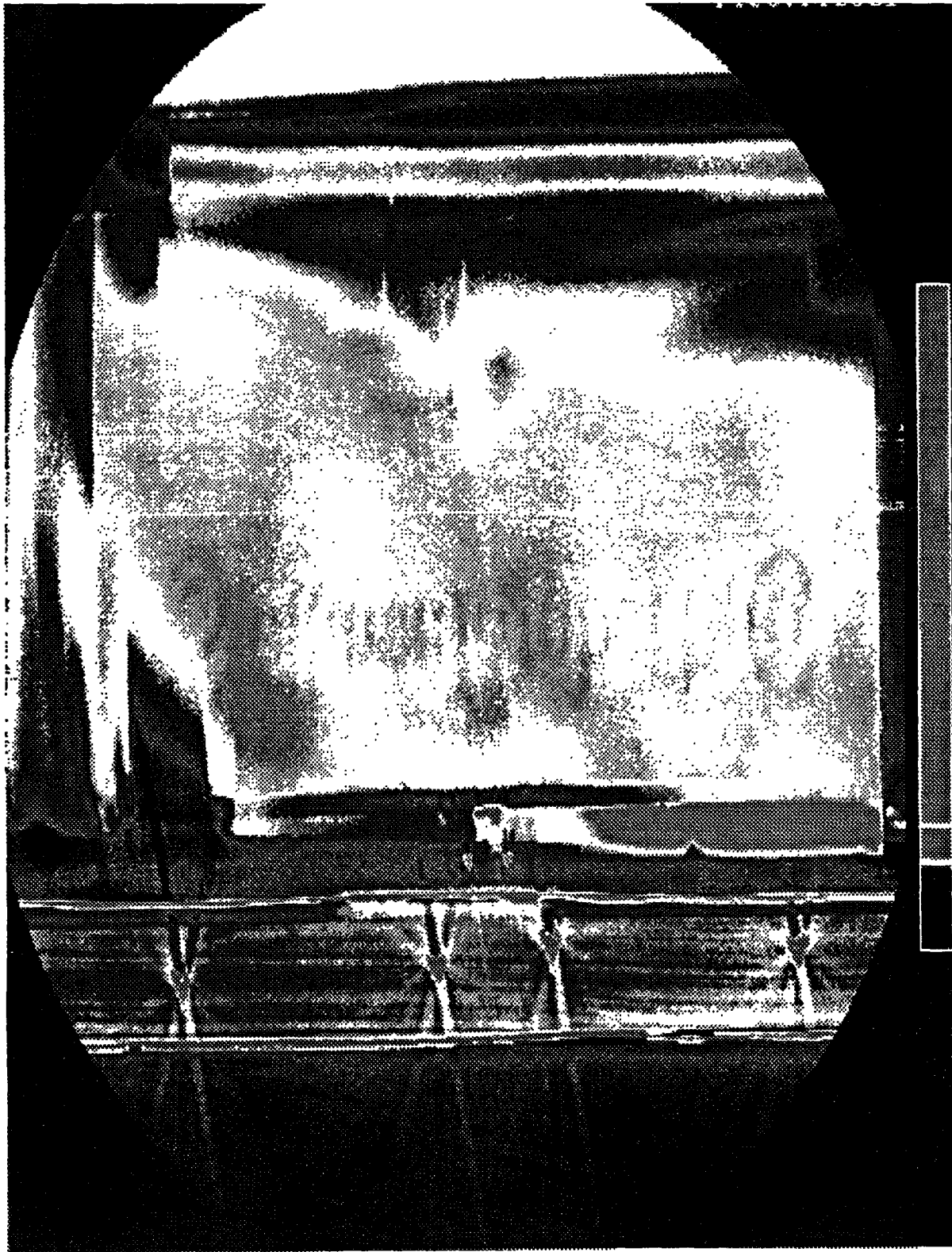
system manufacturers can tailor a system for a specific need at substantially reduced cost. NASA recently purchased an ACTIS-II system, a much smaller and somewhat modified version of ACTIS, at about 5% of the cost of the original system. Interested businesses can often lease large industrial scanners for a few days at a time. Several large industrial scanners are available for lease. If the program is well-planned, this can be a cost-effective way to use ACTIS technology. Finally, if the object under test is small and portable, small businesses can buy CT services at a medical radiology laboratory. NASA did all its early work with CT using a local hospital after-hours. For certain materials, the medical systems actually perform superior to industrial ones.

## CONCLUSIONS:

ACTIS is a versatile inspection tool which has proven useful in addressing many of the problems associated with inspecting complex objects, not only in the government aerospace industry, but other industries as well. NASA has applied this technology to the problems of material science for propulsion systems. A variety of other industries have benefitted from ACTIS technology. ACTIS results are superior to conventional inspection techniques in flexibility, contrast sensitivity, spatial resolution, and visualization. CT inspection typically imposes fewer restrictions on the geometric and other physical features of the object under test. Although CT systems are quite expensive, the results they provide are useful, especially early in the development of new products, by allowing engineers to detect basic design flaws and process anomalies early enough to eliminate them. Small business can take advantage of ACTIS technology in a number of ways: buying a smaller system, leasing and industrial system, or buying time



**Figure 4:** Multi-planar Reconstruction of a Rocket Nozzle Exit Cone clearly represents the location of defects.



**Figure 5:** Unenhanced image from time capsule. Note the faint letters spelling out "Stettiner-Lambert & Co." These letters turned out to be written on a calendar inside the capsule.

on a medical system. Although ACTIS is not the answer to all inspection problems, it provides small business and industry with an excellent tool for building quality into its products.



**Figure 6:** Image of time capsule lid. Utility of ACTIS for lumber industry was discovered here. Note the grain of the wood is visible, as well as separations between planks, and nail locations.

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