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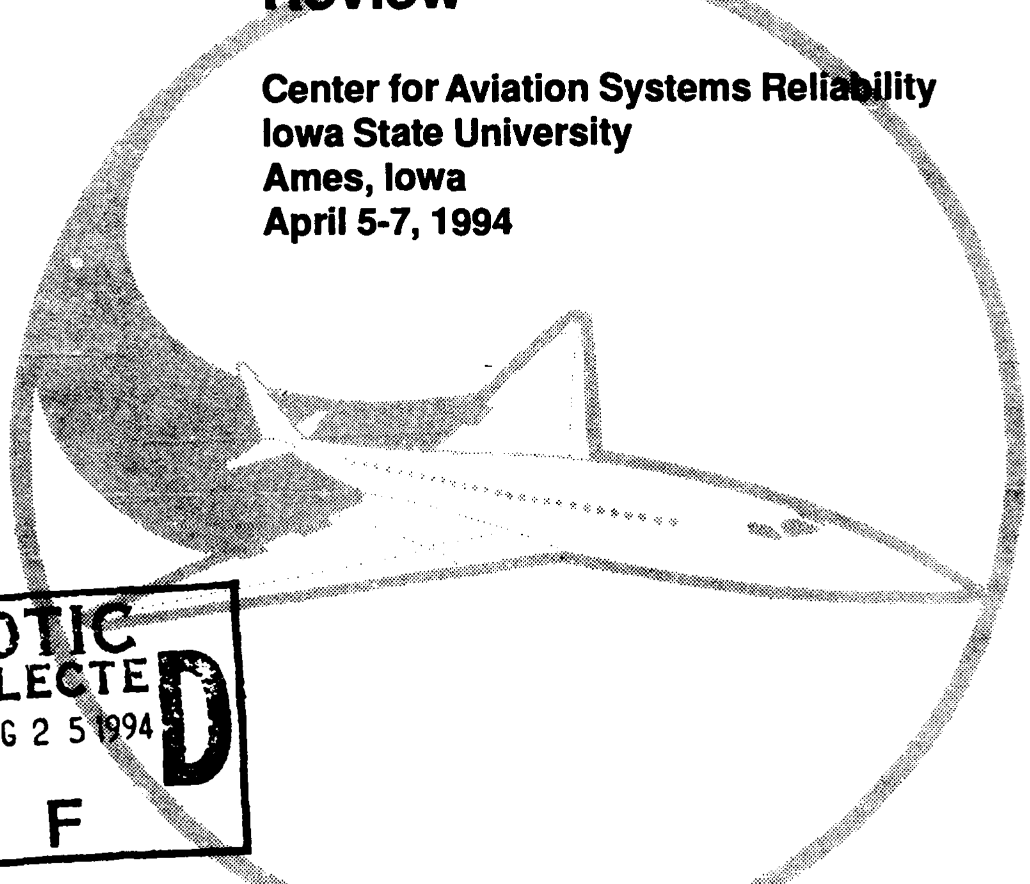
Proceedings of the FAA Inspection Program Area Review



Center for Aviation Systems Reliability
Iowa State University
Ames, Iowa
April 5-7, 1994

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16 Abstract

This publication is a compendium of the Proceedings of the FAA Inspection Program Area Review Presentations given at the Center for Aviation Systems Reliability held at Iowa State University at Ames, Iowa on April 5-7, 1994.

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Proceedings of the FAA Inspection Program Area Review

April 5-7, 1994

*Presentation Material is arranged in order of appearance in the agenda.

The FAA Inspection Program Area Review was sponsored by the Federal Aviation Administration Aging Aircraft Research Program and hosted by the Center for Aviation Systems Reliability at Iowa State University. We gratefully acknowledge the contributions of all participants and extend special thanks to our hosts at Iowa State University.

Executive Summary

The purpose of the Inspection Program Area Review was to solicit program feedback from a broad and diverse base of technical expertise. The invitees to the review included representatives from the airlines, aircraft manufacturers, and the Department of Defense, other experts in the technology of nondestructive inspection, the FAA Aging Aircraft Program managers and staff, members of the Technical Oversight Group on Aging Aircraft (TOGAA), members of the Airworthiness Assurance Nondestructive Inspection Working Group (AANWG), and the Director of the FAA Technical Center.

Because many of the tasks are at a stage of maturity where critical decisions regarding their continuation must be made, and because of the heightened emphasis on technology transfer, the need for responsible feedback is greater than ever. This document is part of an effort to encourage additional constructive criticism.

Aging Aircraft Inspection Program Review
April 5-7, 1994
Center for Aviation Systems Reliability
Ames, Iowa

TUESDAY, APRIL 5

8:00	*Refreshments*	
8:20	**Welcome/Logistics**	Seher/Chimenti
8:30	**Purpose and Goals of Meeting**	Seher/Broz
8:45	**Program Overview**	C. Seher
9:30	**CASR Activities in Last Year**	D. Chimenti
10:15	*Break*	
10:30	**AANC Activities in Last Year**	P. Walter
11:15	**Laboratory Tour and Demonstrations - NSF Lab**	
12:00	*Lunch*	
12:45	**Validation and Tech Transfer**	Walter
	Validation:	
13:10	MOI validation	F. Spencer, SNL
13:30	Cost Benefit Analysis Protocol (with MOI example)	V. Brechling, NWU
13:50	Assessment of Eddy Current Inspection Equipment	F. Spencer, SNL
14:10	Evaluation of Scanners for C-Scan Imaging	W. Shurtleff, SNL
14:30	*Break*	
	Tech Transfer:	
14:50	Tech Transfer Process and Its Implementation on DC9 Wingbox	AANC/McDonnell Dougalss
15:10	Proposed Self Compensating UT Probe Solution for DC9 Wingbox	I. Komsky, NWU
15:30	Prioritized Tech Transfer Candidates (CASR)	CASR directors
16:30	AANC Techg Transfer FY 94- 95 Plans	P.Walter
17:00	*Adjourn*	

WEDNESDAY, APRIL 6

8:00	*Refreshments*	
8:15	**Inspection Reliability and Visual Inspection**	C. Smith, FAA TC
8:25	Eddy Current Inspection Reliability Experiment	F. Spencer, SNL
9:00	Visual Inspection Program	F. Spencer, SNL
9:20	Computational Models for Inspection Engineering	J. Gray, ISU
9:40	*Break*	
10:00	Enhanced Visual Inspection of Fuselage Skins (D-Sight)	J. Komerosky
*	Enhanced Visual Inspection Tools for Airframe Structures	presented as demo only
10:30	**Laboratory Tour and Demonstrations - Individual Labs**	
11:30	*Lunch*	
12:30	**Techniques for Flaw Detection**	C. Smith, FAA TC
	Crack Detection Technology for Fastened Skins:	
12:40	Local Laser Based UT	J. Achenbach, NWU
13:00	Self Compensating UT	I. Komsky, NWU
	Skin Splice Disbond/Corrosion Inspection Technology:	
13:20	Thermal Wave Imaging	R. Thomas, WSU
14:05	Dual Band Infrared Imaging	N. DelGrande, LLNL
14:25	Ultrasonic Characterization of Adhesively Bonded Panels	D. Hsu, ISU
14:45	*Break*	
	Technology for Bond Inspection:	
15:00	Possible Application of LTI's Shearography to Lap Splice Inspections	Dave Galella
15:10	Coherent Widefield Optical Imaging	S. Krishnaswamy, NWU
15:30	Shearographic Inspection	J. Genin, NMSU
15:50	UT Lamb Wave Disbond Detection	J. Rose, Penn State
	Corrosion Inspection Technology:	
*	Eddy Current Methods for Corrosion Detection	presented as demo only
*	Radiographic Methods for Corrosion Detection	not presented
16:50	*Adjourn*	

THURSDAY, APRIL 7

8:00	*Refreshments*	
8:10	**Automation and Robotics**	D. Galella, FAA TC
8:20	Robotic Device for Fastened Skins	W. Kaufman, CMRI
9:00	Neural Nets for Eddy Current Inspection of Wheels & Turbine Blades	Udpa/Peshkin, CASR
9:20	Image Processing for Burner Can Radiography	Walingford/Sahakian, CASR
9:40	*Break*	
9:50	**Training and Information Dissemination**	J. Fabry, FAA TC
10:00	Innovative Process for Technology Transfer	A. Gellman, NWU
10:30	Job Task Analysis	G. Krulee, NWU
10:50	Aviation Inspector Training Course Development	L. Broz, ISU
11:10	X-ray training software	J. Gray, ISU
11:30	**Executive Session: FAA, TOGAA, AANWG only (Lunch: all others)**	
12:30	**Lunch: FAA, TOGAA, AANWG**	
13:00	**Open Feedback to Presentors from FAA, TOGAA, and AANWG**	
13:30	*Adjourn*	

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Record of Inspection Program Area Review
Center for Aviation Systems Reliability, Ames, Iowa
April 5-7, 1994

prepared by
Chris Smith

The summary of participant comments contained in this record is taken from the personal notes of FAA Aging Aircraft Program staff, notes supplied by Lisa Brasche, CASR Assistant Director, and from the evaluation sheets submitted at the end of the review. This record focuses on the comments and discussions during and following the several presentations. Specific technical information on the presentations themselves can be found in the presentation material beginning on page 24.

Attendance and Agenda

The meeting was attended by representatives from the FAA, FAA sponsored researchers, FAA oversight groups, airframe manufacturers, aircraft operators, and other invited guests. All invitees (present or absent) and all participants will have received a copy of these proceedings

An agenda representing the actual sequence of presentations is attached. It differs from the pre-meeting agenda in two primary ways: Chris Seher's talk on 'managing the tech transfer process' was folded into his introductory remarks, and three talks (enhanced tools for visual inspection, x ray inspection for corrosion detection, and eddy current methods for corrosion detection) were deleted from the program due to time constraints. While x-ray backscatter was discussed as a candidate tech transfer activity and an abbreviated presentation on visual inspection aids was presented as part of the laboratory demonstrations, the eddy current task was only mentioned briefly.

General

It is the general consensus of FAA Technical Center personnel that the meeting went very well. Oral and written feedback from Review participants substantiates this judgment. Though there were some significant scheduling difficulties, the majority of inspection program area tasks were both presented and discussed in adequate detail. The predominantly positive tone of the meeting can be seen in the individual comments presented in Appendix H.

In an effort to form a consensus among a broad spectrum of reviewers, FAA Aging Aircraft Program elected to review the inspection program area with both TOGAA and AANWG together. It was also the first real effort to highlight the technology transfer activities of the program area. These two factors in conjunction with our desire to review both inspection and inspection-related programs resulted in a somewhat disconnected and repetitive set of presentations, leaving out some introductory information and leaving out entirely our new starts.

Though the pre-meeting packet (see Appendix C) attempted to alleviate the need for extensive programmatic information, some review participants felt that some additional programmatic information should have been presented. In particular, it was felt that there should have been some discussion of the scope and structure of the inspection program areas and its relationship to other Aging Aircraft program areas.

Several participants commented that there seemed to be too much repetition in the agenda and that they could not distinguish clearly the intent of presentations in 'validation' and those under other topics. The original intent was to select the six to eight most mature and promising technologies for presentation as technology transfer candidates. These presentations were to focus on the *applications* with discussion of the *technology* issues deferred to later in the agenda.

The intent was also to have presenters focus their presentations on 1) progress last year, and 2) plans for tech transfer especially in conjunction with AANC. Because the FAA sponsors and participates in workshops and forums with technical focuses, there was little need to discuss at length the technical foundation of each task at this meeting. FAA management had anticipated that presenters would have prepared more conceptual and less technical presentations.

Scope and Nature of the Inspection Program Area: Because of time constraints the agenda contained only those tasks initiated before March of 1993, leaving out several new starts. This led some participants to question whether the Inspection Program Area has established an adequate balance of long and near term tasks and whether the Program Area through-put was adequately staggered. In fact, the Program Area management does feel that while the balance of long and near term research is adequate, the number of mature near term research tasks as compared to new starts is somewhat high. The 1995 fiscal year budget will be developed with this balance in mind.

During Pat Walter's presentation of the coherent optics work at New Mexico State University it was mentioned that the technology under examination has potential for the computational analysis of strain fields. Though in the context of this review the comment is not very significant, it does raise an issue which is just now being addressed by the Program: In addition to its focus on technologies for detecting flaws likely to be found on in-service aircraft, should the inspection program area use their nondestructive evaluation expertise and resources to directly support the structural integrity program area? Such activities might include the use of coherent optics in the measurement of strain fields around rivets.

Facilities and Resources: Review participants showed significant interest in AANC's sample library. The FAA's chief scientist, Robert Machol, pointed out that the creation and support of a sample library is an activity which may have the added support of the FAA administrator's office.

Other comments on the library focused on its extent, use, and preservation. Issues included:

> The possible role of that sample library in assisting manufacturers in the development of inspection procedures for operators: It seemed to be the prevailing opinion that the interaction of manufacturers and operators with regard to the development of inspection procedures could not be significantly enhanced by AANC's direct participation.
>
> The need for this library to be recognized as a national resource to be used and augmented by a broader range of organizations: The appeal for contributions to the library was again made. While AANC does own and maintain their own samples, they would like to catalog samples owned and controlled by other organizations. Chris Seher repeated his request that FAA contractors and collaborators respond to AANC's request for sample information.
>
> The ability of AANC to preserve specimens in a static state of corrosion. Albuquerque's climate is not likely to significantly change the character of corrosion samples over a several year period.

Validation and Technology Transfer

It became clear to review participants that there are several perspectives on the nature of technology transfer. While Pat Walter did attempt to articulate the issues associated with technology transfer, a formal, coherent, and logical framework is yet to be developed. Because of its complexity it may be appropriate to sponsor an individual review of the technology transfer activities. This would also benefit future inspection program area reviews which usually suffer from time constraints.

Concerns regarding the Technical Center's teaming arrangements with operators, manufacturers, and vendors included the question of who would fund the development of inspection systems past the research and development stage. While commercial interest must pick-up an increasing share of the financial burden as systems move through the technology transfer process, neither the FAA nor AANC has any intention of charging (or ability to charge) individuals or organizations for the use of government resources in the process.

Complicating this issue is that, while the broad mandate of the FAA charges us to foster air commerce, the more specific mandate of the Aging Aircraft Program is focused primarily on safety issues. Based on the broader mandates of the FAA and based on the premise that economics and safety are almost always inseparable, the Aging Aircraft Program management feels that its technology transfer initiatives are entirely appropriate and warranted.

MOI Validation: Review participants expressed significant interest in Floyd Spencer's presentation on the assessment of the Magneto Optic Imager's field performance potential. Many of those concerns are germane to both this assessment and the eddy current inspection reliability experiment (ECIRE), but are more appropriately discussed in conjunction with the latter.

Though specific statements regarding the MOI performance must be carefully qualified, it was generally agreed that its detection performance is roughly comparable to the sliding probe with somewhat shorter inspection times. Because the experimental specimens have a far greater density of flaws than one would expect on in-service aircraft, and because the verification and recording of those flaws is independent of the in MOI device, we cannot at this time make a more definitive statement regarding the time-saving ability of MOI.

Further questions on the maturity of the MOI product and on the need for calibration of the instrument were briefly addressed.

Cost-Benefit Analysis: ATA members took unexpected interest in the presentation of the cost-benefit work. Though a report on generic cost-benefit analyses was scheduled to be used only internally, we have as a result of this interest agreed to release the report to the public. A second report detailing in 'cookbook' fashion the cost benefit procedures (and possibly associated software) are to be released to the public at a later date.

ATA members also expressed some concern that cost-benefit procedures used and distributed by the FAA correspond closely with similar procedures used by operators in evaluating inspection system investments. Steve Erickson feels that the Net Present Value model presently used should be structured in such a way that its results are readily accessible to airline operators. Use of constant dollars - popular among airline operators - is one means of increasing this models accessibility.

It was also pointed out that the FAA's notice of proposed rule making (NPRM) preceding the issuance of any Airworthiness Directive contains a cost impact statement. Any cost-benefit analysis work pursued must at least acknowledge (if not derive from and agree with) this impact statement.

Eddy Current Equipment & Evaluation of Scanners: The 'consumer reports' format and its first two applications (Nortec Eddy Scan and Scanners) were well received. Much of the discussion on Eddy Current Equipment focused on suggestions for expanding the work by examining alternate applications or equipment.

It was suggested that we also apply cost-benefit analyses to our 'consumer reports'. Regarding the first such report, Evaluation of Scanners for C-Scan Imaging in Nondestructive Inspection of Aircraft, Program management had decided that the range of applications was too broad to permit an accurate and useful cost-benefit analysis. The report was designed to allow users with specific applications to make decisions on cost and utility, and not to endorse or condemn particular systems.

Proposed Ultrasonic Inspection of a DC 9 Wingbox T-Cap: The difficulties in technology transfer were quite evident in discussions surrounding the proposed technology transfer of Northwestern University's self compensating ultrasonic probe. Though the service bulletin being investigated for an alternate means of compliance is specific about the procedures to be implemented, a more vague statement of the intent of the inspection lead to some confusion regarding the nature of the flaws to be found. Some time ago McDonnell Douglas substituted in a wing box T cap a 7075 T73 aluminum alloy for the same alloy with a T6 heat treatment which was found to be susceptible to stress corrosion cracking. While the T73 was not as susceptible to stress corrosion cracking it did experience severe exfoliation corrosion and subsequent cracking. It was finally agreed that the intent of the inspection was to locate the corrosion.

Discussions among the participants lead to the general consensus that even if the self-compensating probe is able to detect with sufficient resolution and reliability the corrosion, accept/reject criteria, calibration, and other performance characteristics must be established for the procedure.

Prioritized Technology Transfer Candidates: Aging Aircraft Program staff, CASR and AANC staff, and other collaborators agreed to present for review the following list of technology transfer candidates:

xray densitometers
xrsim
xray backscatter
dripless bubbler
eddy current probe tester
thermal wave imaging

Each candidate was presented with a brief discussion of its intended application and potential for success. Unfortunately, prioritization of this list was not presented or obvious. Other technology transfer candidates were included *ad-hoc* and were neither indicated on the agenda nor listed on the feedback sheets.

The specificity of the indicated applications varies significantly, ranging from very specific (e.g. the DC-9 wingbox T-cap inspection defined by SB 57-98) to rather general (e.g. XRSIM as a tool for inspection engineering or training). In some cases more specificity may be appropriate (e.g. specific application for the thermal wave techniques). In other cases the degree of specificity should remain low, leaving the inspection engineering to organizations better suited to the development of specific applications.

Review participants pointed out several concerns and opportunities overlooked by the some of the technology transfer proposals. It was pointed out that both the dripless bubbler and the xray densitometer were technologies that have been implemented in other forms either commercially or privately. Martin Marietta used a device similar to the dripless bubler for inspection of welds. It was suggested that that device's water containment seals be investigated as a possible improvement to the dripless bubler which is experiencing some durability problems with its present seals.

It was also pointed out that the X-ray densitometer technology is available in a somewhat different form (and for far greater cost) from certain film manufacturers. The experience of that commercial product may be significant interest to our proposed effort.

It is likely that these two situations are not unique. As technologies move closer to commercialization, one would expect that the particulars of product engineering include features which may have been applied to similar products in the past. As such we must be careful to learn from the experience of these products, avoiding redundant solutions or product features which have been shown to be impractical. It was suggested that the formal participation of aircraft operators, aircraft manufacturers, and equipment vendors in a 'strategic partnership' would help to alleviate this potential.

In discussion involving the eddy current probe calibrator it was pointed out that while this system would appear to be of great value, its potential market may be less than ten units. It was therefore suggested that several prototype devices could be built and distributed to the entire set of potential users. Because of the anticipated cost of such a program, this suggestion - or any plan for technology transfer - cannot be seriously entertained without some assurances that the technology is of significant benefit to the aviation industry:

> It was suggested that a reliability study be done to determine the effects of sub-optimal probe configuration on probability of detection.
>
> It was also suggested that John Moulder pursue an ASTM standard for the device. Such a standard would greatly increase the utility of such a device. Some efforts in this area have been made, but other avenues have not been fully explored.

Both of these proposed efforts are under consideration.

The excitement over the potential of AANC to implement technology transfer led some participants to request that the FAA facilitate access to the Validation Center. These proceedings contain an 'information packet' (Appendix D) prepared by AANC for exactly this purpose. Mention of the packet has appeared and will continue to appear in the FAA Quarterly Newsletter.

Inspection Reliability and Visual Inspection

Review participants concluded that Inspection Reliability was a high priority area of research, but felt that the presentation of the material could have been improved. The consolidation of the individual tasks into a coherent program was not evident.

Eddy Current Inspection Reliability Experiment: There were several comments and questions regarding the planning and execution of the eddy current inspection reliability experiment (ECIRE). While some decisions regarding the experiment were questioned, no issues raised at this meeting were left unexamined during the planning phase of this experiment: The selection of controlled and uncontrolled (but observed) variables, the analysis of the Hawthorn effect, and the treatment of false calls were all carefully planned. The three volume set of reports documenting the experiment gives full details of the experiment planning, execution, and analysis.

It is important to note that the probability of detection (POD) curves are parameterized by several controlled and uncontrolled factors. The importance of these parameters on the POD curves is so great that several review participants advised that no POD curve be published without the parameters of that inspection clearly marked on the graph itself.

In addition to the acknowledgment of this parameterization, one must also be aware of the intent of the inspection and the intent of the inspectors. The Boeing procedures used were not intended to ensure the detection of the smallest crack possible. Instead these procedures were designed with the intent of approaching a 'step-function' POD at a certain crack length. Airline inspectors, however, are accustomed to 'out performing' the specification and will typically produce POD curves shifted to the left of this ideal but at the cost of a more gradual transition from 0 to 100 percent probability of detection.

A question which may not have been adequately answered during the presentation involved the handling of false calls and calculation of POD in the absence of complete knowledge of the flaws on the two large specimens. The false call rate was only calculated using data from those panels which were fully characterized and the POD curves, while calculated using all known flaws on both panels, are statistically unaffected by the presence of unknown flaws. (*i.e.* no matter how a subject marked or failed to mark such a flaw, there can be no effect on the POD curve.)

POD curves generated for field inspectors generally showed an upper asymptotic probability of detection of less than unity (100% detection). This was a reflection of the notion that a certain aspect of non-detection is independent of crack size. Such an aspect might include factors such as failure to return to the next sequential rivet after a break or failure to adjust the equipment correctly. It is interesting to note that when this asymptote of the POD curve is less than 0.9 the traditional benchmark of 90 percent detection with 95 percent confidence is a singular point at infinite crack length.

It was pointed out that one of the most generic models for probability of detection in a field environment is a function of three primary factors: 1) human & environment, 2) calibration, and 3) the physical dimensions of crack itself. At the time of presentation it was not made clear whether or not the ECIRE included a universal calibration on a single calibration block. The protocols for the experiment did, in fact, call for this calibration, but the initial report on the experimental data does not include a formal analysis of the effects of calibration on PoD (neither a design factor analysis nor a retrospective analysis). Such an analysis is necessary to do cross-facility comparisons.

It was suggested that the FAA repeat (in a 'quick and dirty' fashion) the ECIRE with a 30 mil calibration standard and a 10 mill calibration standard. This suggestion is under consideration.

Visual Inspection Program: Discussions during and following the presentation of the visual inspection plan indicated that there are still some very significant issues surrounding the approach of the present plan. These issue range from the optimal balance of expertise required to execute the work to the introduction of 'pseudo-flaws' in the AANC 737.

The introduction of 'pseudo-flaws' was discouraged by several participants. Some felt that the concept itself was flawed, and that regardless of their visual similitude to real flaws, inspectors would not acknowledge 'pseudo flaws' as equivalent to real flaws and would not respond to them as they would to real flaws. Others felt that the state of the science - if it existed at all - was not sufficiently advanced to allow this type of experiment at this time. Our knowledge of 'pseudo - flaws' was likened to the initial efforts to simulate cracks with EDM notches.

It was felt by certain participants that the distribution of expertise selected to implement the visual program relied too heavily on individuals with 'human factors' backgrounds. It was suggested that the advisory group include more participation by airline inspectors, and reliability and structural integrity experts. A specific suggestion was to include Ward Rummel on an advisory panel. Both the general suggestion of balancing the distribution of expertise and the specific suggestion of including Ward Rummel on the advisory panel have been accepted.

Visual inspection remains a very high priority for aircraft operators, so it was somewhat disappointing to participants that the visual plan seem to be stuck in Phase 1 (problem definition). One suggestion for 'jump-starting' the program was to use the ECIRE panels and other AANC samples to do a cheap visual detectability study. While such a study would reveal information only on detectability and not probability of detection, it could offer some insight into the nature of the visual inspection process.

There was some concern that visual inspection (as a percentage of aircraft inspection needs) tapers off with aircraft age. The implication is that operators with the least available capital would have the most significant NDI needs.

Discussion originating during the presentation of the visual inspection program lead to additional in depth discussions during the executive sessions. These discussions terminated without resolving some critical questions on nature or extent of visual inspection:

Are visual inspections primarily for crack detection, corrosion detection, or for configuration verification?

For visually inspectable cracks is the crack length the most significant parameter for PoD?

Is the PoD of a non-directed or directed inspection a valid reliability measure?

How much do operators rely on visual detection of cracks? What percentage of all cracks found are found visually? 90%?

Addressing the issue of whether or not the assessment of visual reliability was possible or not, Jess Lewis suggested that we use SDRs and the estimated 400+ Airworthiness Directives per year to identify visual inspection needs, then jump directly to tool development. The generally positive response to the visual aids presentation lends some credibility to this less formal and more empirical approach.

D-Sight: Questions were raised about the interpretation of "signals", PoD, effects of manufacturing variability, and comparison with other wide area techniques.

Computational Models for Inspection Engineering: The presentation was restricted to the X-ray modeling work at CASR which is by far the most advanced. Overall reaction to XRSIM was very positive. The FAA and CASR are presently considering the development of computational models for Eddy Current Inspection and Ultrasonic Inspection.

Technologies for Flaw Detection

In a general response to the projects presented as part of the Technologies for Flaw Detection RPI, TOGAA committee members suggested that we de-emphasize the lap splice. Resources should be redistributed to show more a balance with other multi-site/widespread damage problems. Other options in this area include examination of the tear strap disbond problem.

Steve LaRiviere suggested that the FAA consider the 'bushing hole' problem perhaps using a rotating eddy current probe. Inspection Program Area personnel are presently making efforts to understand the scope and nature of this problem. The assistance of Boeing personnel is being solicited.

While the use of composites on older aircraft is somewhat limited, operators and manufacturers stressed the need for enhanced composite inspection technology. Since composites are used in secondary structure and there is interest in composite repairs to metallic structures, the Aging Aircraft Program will direct some resources to composite inspection problems.

Local Laser Based Ultrasonics: Though the appeal of non-contacting inspection techniques is significant, it was felt that laser based ultrasonics systems (presently used in commercial metal forming applications) are too expensive and not as capable as more traditional techniques.

Thermal Wave Techniques: There was some concern that there was too much emphasis/redundancy on thermal techniques. A better comparison would be between application areas - in this case disbond/corrosion detection in skin splices. While not yet evident the Aging Aircraft Program management is committed to having AANC compare results of work by Joe Rose (Penn State), Bob Thomas (CASR/Wayne State), and Nancy DelGrande (Lawrence Livermore). Joe Rose had, in fact, made mention of an approximate 80% correlation with Thermal Wave Imaging results. A more formal comparison will follow. This comparison will have to be proceeded by a formalization the image interpretation.

Shearography and Coherent Optics: It was mentioned that composites are perhaps the only near team application for shearography and the efforts in this area should be directed largely to composites. Shearography for composites will continued to be pursued as a candidate for near term technology transfer, while opportunities to leverage this technology for metallic structures will be left open. The interpretation of the shearographic images (as pointed out by both presenters and reviewers) is still a very difficult issue. As long as such images require exceptional experience and expertise the technique will not be accepted outside the laboratory.

Regarding the management of the coherent optics work, it was felt that the FAA should encourage greater interaction between Northwestern University and New Mexico State University researchers.

Ultrasonic Lamb Waves for Disbond Detection: The discussion during the Dr. Rose's presentation and the written comments on the review sheets indicate a level of concern regarding the lamb wave research at Penn State. Activities in the next period must focus on the *relative* advantages and capability of the technology. Though a formal comparison of Dr. Rose's AANC results with other techniques could not be made, he did express the judgment that his results did correspond with those of other researcher's results using other technologies.

X-ray inspection: The general distaste for X-ray techniques was again apparent at the Review. It was recommended that we de-emphasize most X-ray efforts except for the work on XRSIM which should be brought to a more advanced stage of technology transfer. The X-ray Backscatter Depth Profilometry technology transfer candidate will not have more resources devoted until after results of workshop scheduled for June.

Automation and Robotics

Robotic Device for Fastened Skins: Concerning the Carnegie Mellon robotics work, participants expressed sentiments ranging from very enthusiastic to somewhat apprehensive. This is almost certainly attributable to the perceived uncertainty in its risks and potential associated with its immature state. While it was suggested that a cost-benefit analysis might allay some of these concerns, it was concluded that there exists insufficient data at this time. Carnegie Mellon will, however, coordinate with Venessa Brechling of Northwestern University Transportation Center in efforts to collect the necessary data for a proposed FY 95-FY96 cost benefit analysis.

In response to a question, representatives from CMRI estimated the cost of the robot (reproduction of the prototype with no additional engineering) to be about $10,000 for the robot hardware and about $35K for the software and computer hardware. While these figures would of course depend on the features incorporated, CMRI has made an effort to use only off-the-shelf technologies to keep the anticipated cost of the system low.

It was mentioned that at least two other organizations were involved in the development of such robots, and that CMRI should be in contact with these organizations and that CMRI should relate their prototype to products from commercial firms (Benthos, Seattle?) and a system under development at NIST. It was also suggested that the FAA conduct a formal industry-wide survey to assess the potential for automation in the aircraft maintenance environment.

Neural Nets: Some questions arose regarding the need for neural nets software for wheel inspection. While certain signal analysis issues still exist, most participants were reluctant to endorse an 'ignorance-based' method, preferring instead more explicit signal analysis/enhancement techniques. United has apparently elected to address their wheel inspection needs with a more conventional system. Nevertheless the approach is technically sound, being used already in the nuclear power industry.

Training and Information Dissemination

The area of training and information dissemination, and specifically the training task itself, were identified high priorities by Review participants. Nevertheless there is a strong divergence of opinion regarding the Aging Aircraft Research Program's potential for contribution in this area. Some participants seemed to be interested in a program with broader scope (not just training for FAA Aviation Safety Inspector) involving the coordination with or participation by industry. The FAA, on the other hand, is reluctant to engage in any major program without a clear specification of need and the potential for direct and substantial benefits to the FAA.

Illustrative of this concern is a comment which questioned the propriety of the FAA's involvement in the later stages of technology transfer (commercialization): Is this a conflict of interest? Will political instead of economic forces drive the process? Shouldn't Flight Standards make a specific call for overhaul of 65 5 197 citing specific deficiencies before the Technical Center addresses the problem?

It was suggested that any training course development also include material recently documented in the report, Emerging Nondestructive Inspection Methods for Aging Aircraft.

Innovative Process for Technology Transfer: This task also drew a wide variety of responses. One very specific response listed two sets of potential case-studies:

- successful technology transfer:
  - low frequency eddy current
  - automated bolt hole inspection,
  - shielded pencil probe
  - video probe
  - sliding probe
- unsuccessful technology transfer:
  - acoustic emissions

Aviation Inspector Training Course: The response to the training effort was overwhelmingly positive. The approach of using an 'expert design panel' was suggested as a basis for other FAA training. While the training was developed specifically for FAA Aviation Safety Inspectors, operators expressed in acquiring the materials for their own commercial training.

Summary of Score Sheets
and
Results of the Review

The purpose of the review was to obtain sufficient feedback to optimally direct the FAA Aging Aircraft Program's Inspection Program Area. The feedback was received as written and oral comments, and numerical/letter scores associated with each program area or task. Just as we allow no single individual or group to dictate the program, we allow no single medium of feedback undue influence.

The following conclusions are drawn from the score sheets alone:

Technology Transfer Process and Its Implementation is one of the highest priority initiatives. There is some concern that this program initiative requires a better approach/implementation.

Aviation Inspector Training is one of the highest priority activity of those reviewed. It is also being executed and managed very well.

The **Visual Inspection Program** is a very high priority. There is, however, a general consensus that the project requires significant redirection.

Innovative Process for Technology Transfer is a high priority task, which is being executed well.

Eddy Current for Corrosion is a high priority task, which is being executed well. (This tasks, however, was not presented to the whole group, and as a result there were only 7 reviewers who chose to comment.)

Both DC-9 and DC-10 applications for **Self-Compensating Ultrasonic Device** are high priority tasks and strong candidates for technology transfer.

The **Low Cost Photodensitometer** technology transfer candidate has significant technology transfer potential, but its utility (priority) to the aviation industry is limited.

X-ray Backscatter for Corrosion Detection is a low priority with the little potential for near-term technology transfer.

Neural Nets for Wheel Inspection is low priority. There is a general consensus that the project requires significant redirection.

many reviewers feel that **D-Sight for Corrosion Detection** is low priority and that the project requires redirection. There is, however, a wide diversity of opinion on this task.

Coherent Optics/Shearography The technology is seen as having little near term potential. Current efforts are considered a medium to low priority and require some redirection.

Thermal Techniques for Disbonds and Corrosion are not viewed as strong near term technology transfer candidates.

The comments received both in writing and orally support these statements. In some cases program management had already made plans to change the task scope, direction, or resources to address these concerns. In those other cases, program management is committed to examining the issues in conjunction with our sponsors.

Scope and Nature of the Inspection Program Area: While we do have a complete consensus on the scope and nature of the Inspection Program Area, we feel that a core program involving technologies with a two-year 'incubation' period fed by 10-15% long term research at one end and supplying input to a technology transfer program at the other is an appropriate approach.

Program management will examine of the relationship and interaction of the Inspection Program Area with the Structural Integrity Program Areas within the Aging Aircraft Program. No specific ideas for closer interaction have been suggested.

Technology Transfer: The review emphasized the need for careful planning and execution of technology transfer activities. We expect no formal change in the program, but do expect to be exercising close oversight and frequent review.

Specific information on the several technology transfer candidates will be published in the upcoming issues of the NAARP News.

Visual Inspection: In response to the review, a visual inspection meeting was held in Albuquerque on May 24 & 25. The team assembled in Albuquerque included several ATA members and Ward Rummel. The results of that meeting will be discussed in the next issue of the NAARP News.

Composites: The Aging Aircraft Program supports research on the inspection of composites if an aging aircraft inspection application can be identified *or* if a technology with aging aircraft applications can be leveraged to support composite inspection.

Program Redundancy: Two areas were identified as requiring better communication between researchers, redirection of parallel efforts, or cancellation of redundant efforts: coherent optics and thermal techniques. In examining the allocation of resources to specific program elements program management has three goals:

restructuring the program to remove redundancy

fairly allocating resources to application areas

fairly allocating resources to technology areas

Explanation of Inspection Review
Feedback Synthesis

The following three tables contain a numerical synthesis of the feedback scores. The first table contain data on the reviewers' assessment of the priority of the initiatives/tasks, the second table contains data on the reviewers' assessment of the approach/execution of the initiatives/tasks, and the third table contains data on the reviewers' assessment of the technology transfer potential of the initiatives/tasks. Each table contains the number of responses (resp), average response (avg), and standard deviation (sdv) for each of the initiatives/tasks scored in that area. All data is sorted by average score in descending order.

The numerical equivalent of the ratings given by each participant are as follows:

The priority score is an assessment of the initiative's importance.

0 = no requirement
1 = low priority
2 = medium priority
3 = high priority

The approach/execution score is an assessment of the initiatives approach and success to date. The grade should be considered reflective of both task management and technical merit.

4 = excellent, no redirection required
3 = good, but consider some redirection
2 = fair, but significant redirection is necessary
1 = borderline acceptable, major restructuring or cancellation
0 = no merit, cancellation imperative

The technology transfer score is an assessment of the importance of and potential for engaging in near-term technology transfer.

2 = Immediate tech transfer candidate
1 = consider tech transfer in FY95 after some additional development
0 = no tech transfer possible in near- to mid-term, long term only (if any).

Review Responses by Activity Priority

Area	RPI/Task	resp	avg	sdv
Demonstration and Validation	Tech Transfer Process and Its Implementation	18	2.94	0.24
Training & Info Dissemination	Aviation Inspection Training Course Dev	12	2.92	0.29
Overall Program Element	Validation and Tech Transfer	18	2.89	0.47
Technology Transfer Candidate	Self-Compensating UT for DC9 Wingbox	21	2.86	0.36
Overall Program Element	Inspection Reliability andVisual Inspection	12	2.83	0.40
Visual Insp and Insp Reliability	Visual Inspection Program	24	2.81	0.48
Overall Program Element	Techniques for Flaw Detection	7	2.79	0.39
Technology Transfer Candidate	Self Compensating UT for DC10 Spar Cap	21	2.71	0.56
Technologies for Flaw Detection	Eddy Current Methods for Corrosion	7	2.71	0.49
Training & Info Dissemination	Innovative Proc for Tech Trsfr	21	2.71	0.72
Training & Info Dissemination	X-ray Training Software	12	2.71	0.45
Technologies for Flaw Detection	Self Compensating Ultrasonics Probe	27	2.70	0.47
Training & Info Dissemination	Task Analysis/Visual Task Descrptrs	17	2.65	0.49
Overall Program Element	Training & Information Dissemination	8	2.63	0.52
Demonstration and Validation	Cost Benefit Analysis Protocol w/MOI Example	26	2.62	0.70
Visual Insp and Insp Reliability	Enhanced Visual Insp Tools for Airframes	13	2.62	0.65
Visual Insp and Insp Reliability	Eddy Current Inspection Reliability Experiment	24	2.60	0.77
Technologies for Flaw Detection	Ultrasonic Characterization of Adhesive Bonds	24	2.54	0.57
Technology Transfer Candidate	UT w/Dripless Bubbler and Low Freq Probe	25	2.52	0.57
Demonstration and Validation	Assessment of EC Inspection Equipment	24	2.50	0.51
Technologies for Flaw Detection	Thermal Wave Imaging	27	2.44	0.63
Demonstration and Validation	Assessment of Scanners for C-Scan Imaging	25	2.34	0.62
Demonstration and Validation	MOI Validation at AANC	27	2.31	0.87
Overall Program Element	Automation and Robotics	7	2.29	0.49
Technology Transfer Candidate	Thermal Wave Imaging	23	2.28	0.69
Technology Transfer Candidate	Probe Calibration and Standards	24	2.25	0.79
Automation and Robotics	Radiography for Corrosion Detection	8	2.13	0.64
Technologies for Flaw Detection	Shearographic Inspection Modeling	23	2.09	0.67
Automation and Robotics	Robotic Devices for Fastened Skins	25	2.08	0.86
Visual Insp and Insp Reliability	Computer Codes for Inspection	22	2.07	0.79
Technology Transfer Candidate	Shearographic Inspection for Disbonds	18	2.06	0.64
Automation and Robotics	Neural Nets for Wheel Inspection	23	1.96	1.07
Technologies for Flaw Detection	Coherent Widefield Optical Imaging	22	1.95	0.58
Technologies for Flaw Detection	Ultrasonic Lamb Wave Disbond Detection	20	1.95	0.69
Visual Insp and Insp Reliability	Enhanced Visual Insp for Corrosion using D-sight	24	1.94	0.89
Technologies for Flaw Detection	Dual Band Infrared Imaging	23	1.93	0.73
Automation and Robotics	Image Processing for X-ray	24	1.92	0.93
Technology Transfer Candidate	Low cost Photodensitomerter for X Ray Imaging	16	1.88	0.62
Technologies for Flaw Detection	Local Laser Based Ultrasonics	25	1.82	0.83
Technology Transfer Candidate	X-ray Backscatter for Corrosion Detection	25	1.54	0.68

Review Responses by Approach/Execution Score

Area	RPI/Task	resp	avg	sdv
Training & Info Dissemination	Aviation Inspection Training Course Dev	11	3.82	0.60
Training & Info Dissemination	X-ray Training Software	13	3.77	0.44
Training & Info Dissemination	Innovative Proc for Tech Trsfr	16	3.72	0.52
Technologies for Flaw Detection	Eddy Current Methods for Corrosion	6	3.66	0.82
Visual Insp and Insp Reliability	Eddy Current Inspection Reliability Experiment	27	3.52	0.58
Technologies for Flaw Detection	Self Compensating Ultrasonics Probe	27	3.48	0.64
Technologies for Flaw Detection	Ultrasonic Characterization of Adhesive Bonds	24	3.44	0.71
Visual Insp and Insp Reliability	Enhanced Visual Insp Tools for Airframes	10	3.30	1.06
Overall Program Element	Validation and Tech Transfer	17	3.24	0.90
Demonstration and Validation	MOI Validation at AANC	27	3.22	0.68
Overall Program Element	Techniques for Flaw Detection	7	3.21	0.70
Training & Info Dissemination	Task Analysis/Visual Task Descrptrs	14	3.21	0.89
Overall Program Element	Training & Information Dissemination	5	3.20	0.84
Demonstration and Validation	Assessment of Scanners for C-Scan Imaging	22	3.18	0.96
Technologies for Flaw Detection	Ultrasonic Lamb Wave Disbond Detection	18	3.14	1.03
Technologies for Flaw Detection	Thermal Wave Imaging	25	3.10	1.04
Demonstration and Validation	Assessment of EC Inspection Equipment	23	3.08	0.65
Automation and Robotics	Robotic Devices for Fastened Skins	23	3.07	0.77
Technologies for Flaw Detection	Coherent Widefield Optical Imaging	22	3.02	1.22
Demonstration and Validation	Cost Benefit Analysis Protocol w/MOI Example	27	3.00	0.97
Visual Insp and Insp Reliability	Computer Codes for Inspection	22	3.00	0.87
Technologies for Flaw Detection	Dual Band Infrared Imaging	21	2.95	0.85
Technologies for Flaw Detection	Shearographic Inspection Modeling	22	2.93	1.12
Automation and Robotics	Radiography for Corrosion Detection	5	2.90	0.89
Technologies for Flaw Detection	Local Laser Based Ultrasonics	25	2.88	0.96
Automation and Robotics	Image Processing for X-ray	23	2.87	0.93
Overall Program Element	Automation and Robotics	7	2.86	0.69
Demonstration and Validation	Tech Transfer Process and Its Implementation	13	2.85	1.14
Automation and Robotics	Neural Nets for Wheel Inspection	23	2.74	1.33
Visual Insp and Insp Reliability	Enhanced Visual Insp for Corrosion using D-sight	21	2.52	1.09
Overall Program Element	Inspection Reliability andVisual Inspection	12	2.42	0.93
Visual Insp and Insp Reliability	Visual Inspection Program	21	2.29	0.73

Review Responses by Technology Transfer Potential

Area	RPI/Task	resp	avg	sdv
Technology Transfer Candidate	Self-Compensating UT for DC9 Wingbox	19	1.76	0.54
Technology Transfer Candidate	Self Compensating UT for DC10 Spar Cap	19	1.71	0.56
Technologies for Flaw Detection	Self Compensating Ultrasonics Probe	25	1.56	0.57
Technology Transfer Candidate	Probe Calibration and Standards	20	1.53	1.04
Technology Transfer Candidate	UT w/Dripless Bubbler and Low Freq Probe	22	1.45	0.58
Technologies for Flaw Detection	Ultrasonic Characterization of Adhesive Bonds	23	1.26	0.69
Technology Transfer Candidate	Shearographic Inspection for Disbonds	15	1.20	1.32
Automation and Robotics	Image Processing for X-ray	19	1.18	0.77
Technologies for Flaw Detection	Eddy Current Methods for Corrosion	7	1.14	0.75
Automation and Robotics	Neural Nets for Wheel Inspection	21	1.10	0.83
Technologies for Flaw Detection	Thermal Wave Imaging	22	0.91	0.80
Technology Transfer Candidate	Thermal Wave Imaging	19	0.89	0.81
Technologies for Flaw Detection	Ultrasonic Lamb Wave Disbond Detection	17	0.85	0.84
Technologies for Flaw Detection	Dual Band Infrared Imaging	21	0.81	0.81
Automation and Robotics	Radiography for Corrosion Detection	5	0.80	0.83
Technology Transfer Candidate	Low cost Photodensitomerter for X Ray Imaging	13	0.73	0.78
Technologies for Flaw Detection	Coherent Widefield Optical Imaging	20	0.60	0.77
Technologies for Flaw Detection	Shearographic Inspection Modeling	20	0.53	0.75
Technology Transfer Candidate	X-ray Backscatter for Corrosion Detection	21	0.43	0.75
Technologies for Flaw Detection	Local Laser Based Ultrasonics	24	0.42	0.64
Automation and Robotics	Robotic Devices for Fastened Skins	21	0.29	0.56

Presentation Materials

Inspection Program Area Review

April 5-7, 1994, Ames, Iowa

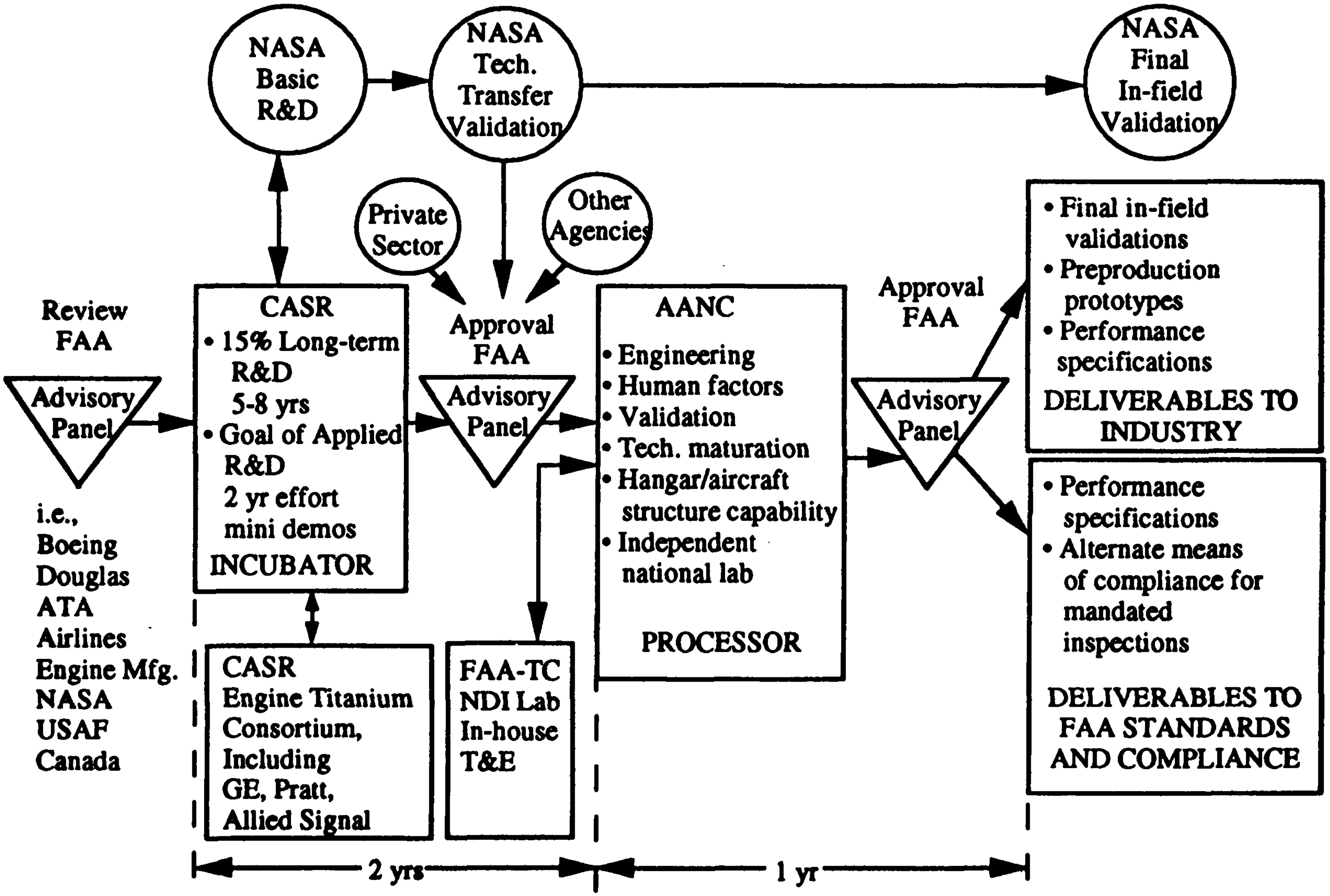
INSPECTION PROGRAM AREA REVIEW

APRIL 5 - 7, 1994

CENTER FOR AVIATION SYSTEMS RELIABILITY

AMES, IOWA

CHRIS SEHER



NASA Basic R&D
NASA Tech. Transfer Validation
NASA Final In-field Validation
Private Sector
Other Agencies
Review FAA
Advisory Panel
i.e., Boeing Douglas ATA Airlines Engine Mfg. NASA USAF Canada
CASR
• 15% Long-term R&D 5-8 yrs
• Goal of Applied R&D 2 yr effort mini demos
INCUBATOR
Approval FAA
Advisory Panel
CASR Engine Titanium Consortium, Including GE, Pratt, Allied Signal
FAA-TC NDI Lab In-house T&E
AANC
• Engineering
• Human factors
• Validation
• Tech. maturation
• Hangar/aircraft structure capability
• Independent national lab
PROCESSOR
Approval FAA
Advisory Panel
• Final in-field validations
• Preproduction prototypes
• Performance specifications
DELIVERABLES TO INDUSTRY
• Performance specifications
• Alternate means of compliance for mandated inspections
DELIVERABLES TO FAA STANDARDS AND COMPLIANCE
2 yrs
1 yr

April 1993 - March 1994

Inspection Related Conferences And Workshops

May

18 May 18 - May 19 Acoustic Emissions Workshop, Johns Hopkins University

June

2 Jun 2 - Jun 3 Thermal Wave Imaging Workshop, Lawrence Livermore National Labs

22 Signal Processing Workshop, NASA Langley

30 Coherent Optics & Enhanced Visual Ipsection Workshop, Atlantic City, New Jersey

July

22 Jul 22 - Jul 23 Ultrasonic, Eddy Current, & Radiography Workshop, Northwestern University

September

1 Sep 1 - Sep 2 Inspection Reliability Workshop, Atlantic City, New Jersey

20 Sep 20 - Sep 23 ATA NDT Forum, Scottsdale, Arizona

October

12 TOGAA Review, Burlington, Massachusetts

February

22 Infrared Presentation & Tutorial

March

2 Mar 2 - Mar 4 Engin Titanium Consortium Review, West Palm Beach, Florida*

14 Mar 14 - Mar 18 Thermal Wave Imaging at SNL
Mar 14 - Mar 17 SAE Airframe Maintenance Conference, Ontario, California

21 Mar 21 - Mar 25 ASNT Spring Conference, New Orleans
Mar 21 - Mar 23 Tech Transfer Meeting (Walter, Chimenti, Others)

April 93

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May 93

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June 93

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July 93

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August 93

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29	30	31				

September 93

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October 93

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31						

November 93

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December 93

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January 94

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23	24	25	26	27	28	29
30	31					

February 94

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27	28					

March 94

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27	28	29	30	31		

GENERAL CONCERNS OF REVIEW PARTICIPANTS

comments	response
Information exchange in the interim between meetings and in preparation of meetings should be improved.	A quarterly news letter is now being published. Response to this newsletter has been very positive. The information packet sent out in preparation of the meeting should have provided sufficient preparation material for this meeting.
To justify their attendance at these reviews, participants must be given more than vague assurances of the FAA's intentions to improve the program.	This review will strive to provide both hard technical results (in the form of technical documentation) and timely oral and written feedback.
The program should be presented with 'road maps' to give an overall picture of the program.	In this review, each RPI manager will present similarly structured overview of his program area. These presentations will utilize gantt charts and summary sheets to present the program area as a cohesive, coordinated program with prioritized tasks.
The agenda should cut down on the amount of program management presentation.	The agenda was developed with this comment in mind. We welcome comments on whether or not we succeeded. General program information is available with the rest of the documentation being offered.
Some of the technologies presented (in particular thermal techniques) showed results without sufficient time devoted to the explanation and interpretation of those results.	Some presentations dealing with interpretative results (C-scan images) are being given additional time for explanation and discussion.

REVIEW PROGRAM GOALS, APPROACH, AND MANAGEMENT

comments	response
Technology transition is the Aging Aircraft Program's biggest problem.	Technology Transfer has been identified at the highest priority. Program efforts and accomplishments in this regard will be a constantly underlying theme of this review.
RPI's must be acknowledged as the defining document of the program.	The program is now under strict control of the RPIs and presentations representing the program reflect the RPI structure.
FAA must become aware of other government and privately sponsored programs. Research must not be duplicated. Thermal imaging is done by both FAA and NASA	Efforts to coordinate the program with NASA and Air Force Programs are well underway. AANC is presently developing a mutually beneficial relationship with the US Coast Guard. A Thermal Imaging Workshop was held at Lawrence Livermore in which NASA and FAA coordinated their activities.
Sandia should emphasize its role as a validation and demonstration center.	AANC has completed at least 33 demonstration validation activities in the last year. The continuous enhancement of their sample library and the baselining of the 737 should facilitate this activity even more.
Commuter concerns are still not adequately addressed. The FAA should consider some activity addressing penetrant and magnetic particle inspections. Training is a primary concern of operators of commuter aircraft.	Though the present RPIs do not reflect commuter concerns, we are committed to working with Bob Sexton (through Fred Sobeck) to identify these concerns in the next generation of RPIs. Commuter training issues are presently being pursued by CASR.

REVIEW OF TASK AREA

comments	response
Examine the bond inspection initiatives to ensure that its results are not just specific to Boeing aircraft.	Disbond detection technologies have been separated into those technologies which address corrosion and disbonds and those which address only disbond. It is anticipated that this separation will aid in the identification of specific aircraft applications.
The visual program needs redirection. Work on visual enhancement should focus on structured light concepts. Worthwhile information from SDR/Boeing/Japanese databases is limited.	Work on the database analysis of SDR reports has been idled. Work on development and tech transfer of visual aids (specifically structured light) has been increased. A visual program plan is now in place.
Inspection reliability efforts should focus on false calls.	We believe the correct balance of POD, false call, and other reliability measures are present in the Eddy Current Inspection Reliability Reports. We welcome comments on these documents and our approach.
The eddy current inspection reliability experiment should serve as a model for further equipment/technique reliability evaluations.	The protocol documents have been widely distributed to achieve exactly this end. Visual Inspection Reliability experiment planning is - to a large extent - based on the ECIRE protocols. Other AANC experimental work is taking advantage of both procedures and samples prepared for this experiment. The results of the ECIRE suggest that on-site inspection experiments can in many cases be replaced with well planned experiments at AANC.
Technologies producing C-Scan images should devote some effort the to creation of permanent records.	While technical issues remain, political issues associated with the retention of such records must resolved first.

REVIEW OF TASK APPROACH AND MERIT

comments	response
The energy sensitive x-ray work needs to be re-evaluated for its contribution to the program. Redirection to address specific commuter problems may be appropriate.	The energy sensitive sensors projects has been combined with the x-ray backscatter work to produce (in the near term) a prototype one-sided, low radiation hazard device for verification of hidden corrosion (not just air gaps). Though we feel we have a prototype device that is appealing to industry, we have not identified a specific commuter application.
ISU's neural nets work needs redirection. The wheel inspection application is not considered by industry to be critical and may not have been the best choice for a test bed.	After evaluating the program we proceeded in a slightly modified direction. While the change may not have been as drastic as some critics would have liked, we feel the present results and industry support are sufficient to continue in the direction we are moving.
While technically appealing, the self compensating ultrasonic device has not progressed substantially in two years, nor has it identified a specific application. This is one of few technologies being developed with increased crack resolution capability and should be validated for MSD size cracks -- perhaps on ECIR experiment panels.	This project is now our premier tech transfer activity. Specific applications and beneficiaries have been identified.
While the coherent optics work is technically credible, the 'fine tuning' of the technology seems to be arbitrary in nature. Efforts should be redirected to address technology transfer and commercialization. Industry sponsors must be identified.	Industry is beginning to show some interest in shearography and coherent optical technologies. LTI has licensed technology from Northwestern. We will continue to work in areas in which the industry shows the most interest.
Produce 'consumer report' on modular automatic scanning systems.	Copies of a draft version of this report are available here today for distribution.

PROGRAM OVERVIEW

DALE CHIMENTI
FAA-CASR
IOWA STATE UNIVERSITY

FAA
Center for Aviation Systems Reliability

FAA-CASR

Iowa State University
Northwestern University
Wayne State University
Tuskegee University

Engineering Research Development and Application	Education and Training	Engine Titanium Consortium

FAA-CASR

FAA
Center for Aviation Systems Reliability

Defining Characteristics of FAA-CASR R&D

- Problem focussed, 2-3 year efforts targeted for implementation
- NDE techniques developed as quantitative measurement tools.
- Laboratory tests and techniques pre-validated by comparison with theory and mini-demos.
- Data presentation schemes selected for compatibility with automated instrumentation.
- Technology transfer schemes pre-planned.

FAA
Center for Aviation Systems Reliability

Objectives

- To develop quantitative nondestructive evaluation methods for aircraft structures and materials including prototype instrumentation, software, techniques and procedures

- To develop and maintain comprehensive education and training programs specific to the inspection of aviation structures including both theory and practice components

FAA CASR

FAA Center for Aviation Systems Reliability

CASR INDUSTRIAL INTERACTIONS

XRSIM, X-ray POD	FAA Tech Center, Boeing, Douglas, GE, NWA
Realtime X-ray Enh	DL, NWA, Northstar Imaging
Thermal Waves	AANC, NWA, Tinker AFB (ARINC), Lockheed-Georgia, Saudi Air
Neural Nets	UAL, NWA, Garrett, BF Goodrich, ABS, Candec
Dripless Bubbler	NWA, McDonnell-Douglas, Boeing, USAir, AANC(4/20-21)
Self-Comp Probe	Douglas, NWA, UAL

FAAREV ISU 4-94

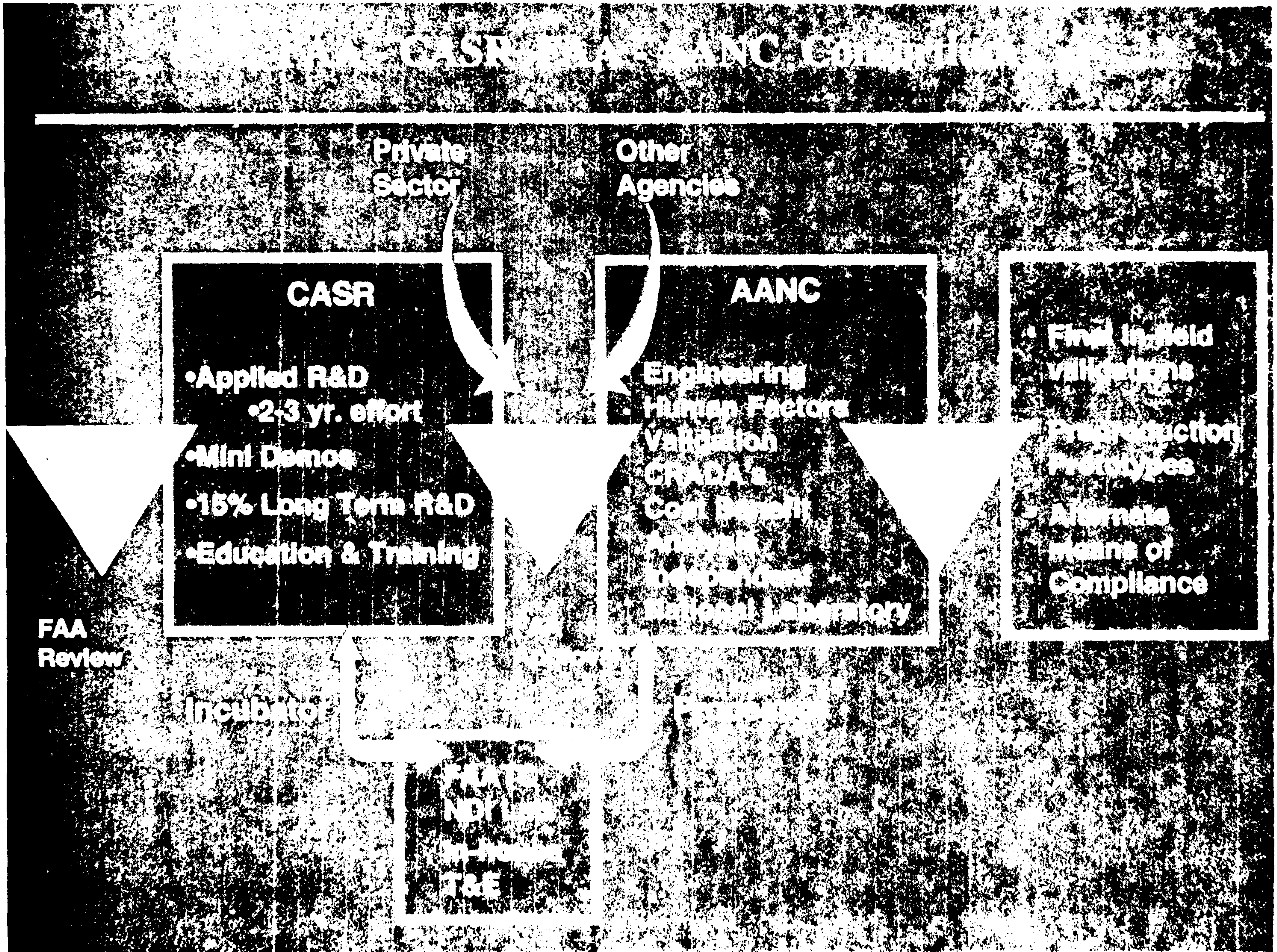
FAA CASR

FAA Center for Aviation Systems Reliability

CASR INDUSTRIAL INTERACTIONS (con't.)

EC Corrsn Detection	Boeing, Douglas, CAF
EC Calib. Corp,	Boeing, NWA, UAL, GE, NDT Engineering
	Zetec
X-ray BDP	UAL, DL, AANC
Training	UAL, AA, NWA, NWAirlink, USAir, TWA, DL, FAA-TA, EPRI, FAA Regional Offices
ESPI	Laser Technology Inc (LTI)

FAAREV ISU 4-94

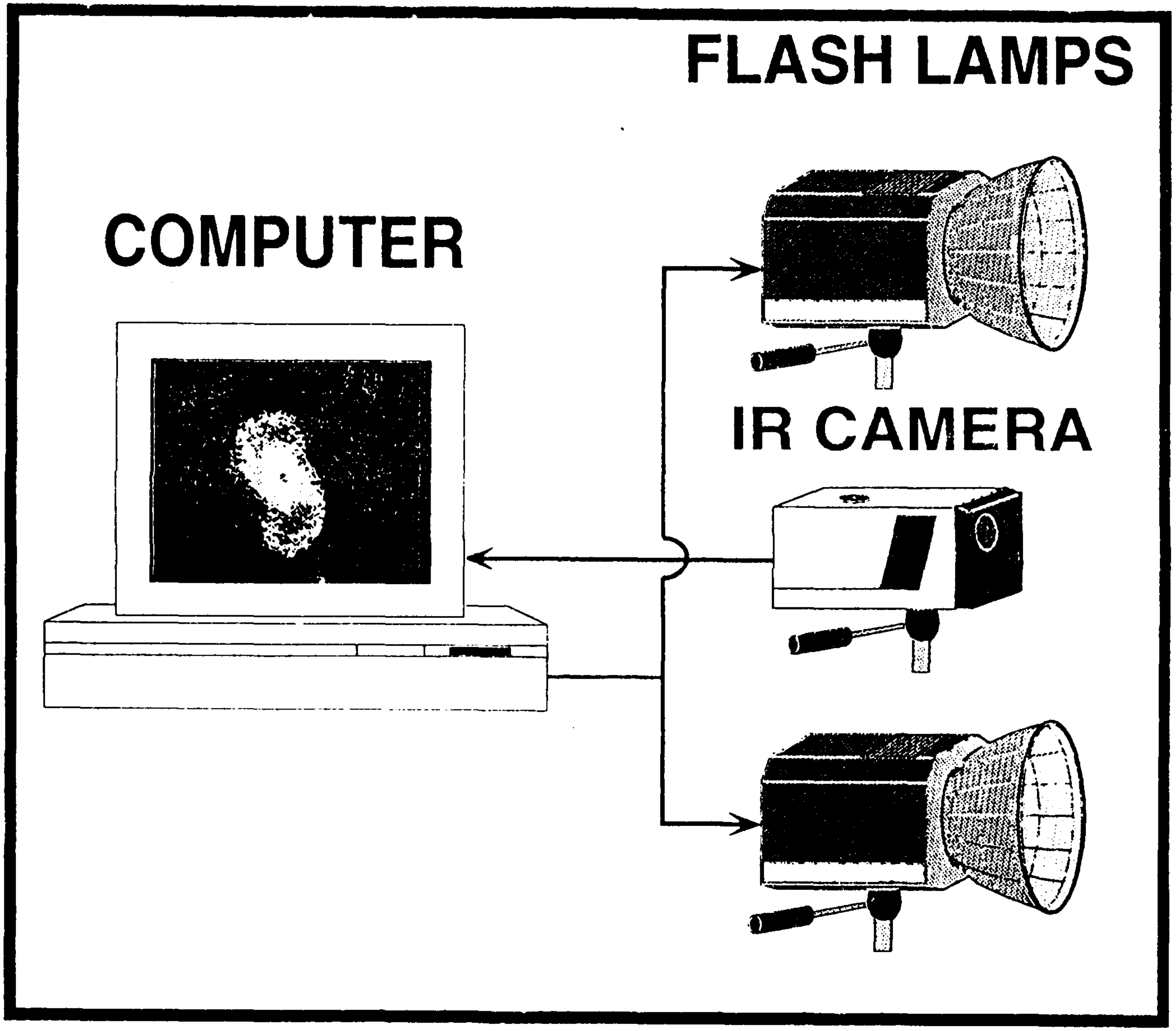

Private
Sector
Other
Agencies
CASR
•Applied R&D
•2-3 yr. effort
•Mini Demos
•15% Long Term R&D
•Education & Training
AANC
Engineering
Human Factors
Validation
CRADA's
Cost Benefit
Compliance
FAA
Review
Incubator
T&E

TECHNIQUES FOR FLAW DETECTION
RPI 199

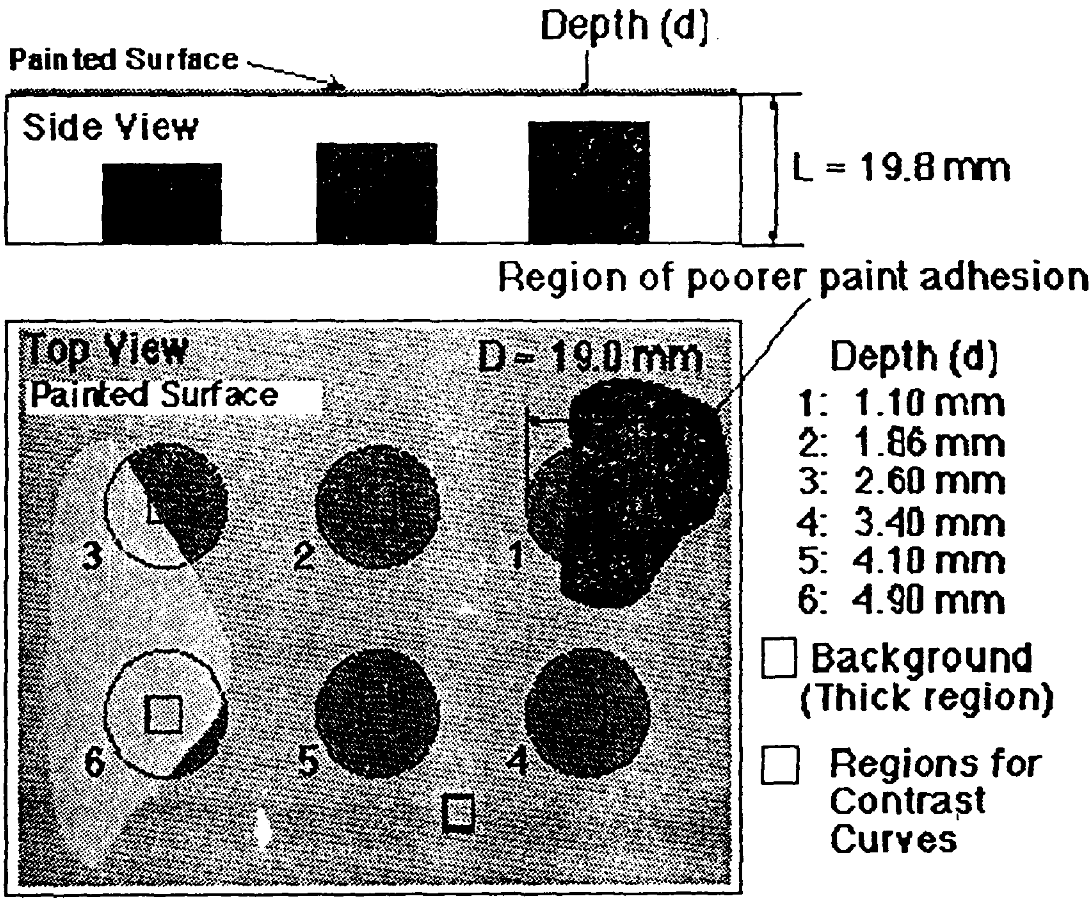
Tech Area: Adhesively Bonded and Composite Structure

Thermal Waves Imaging of Adhesive Bonds

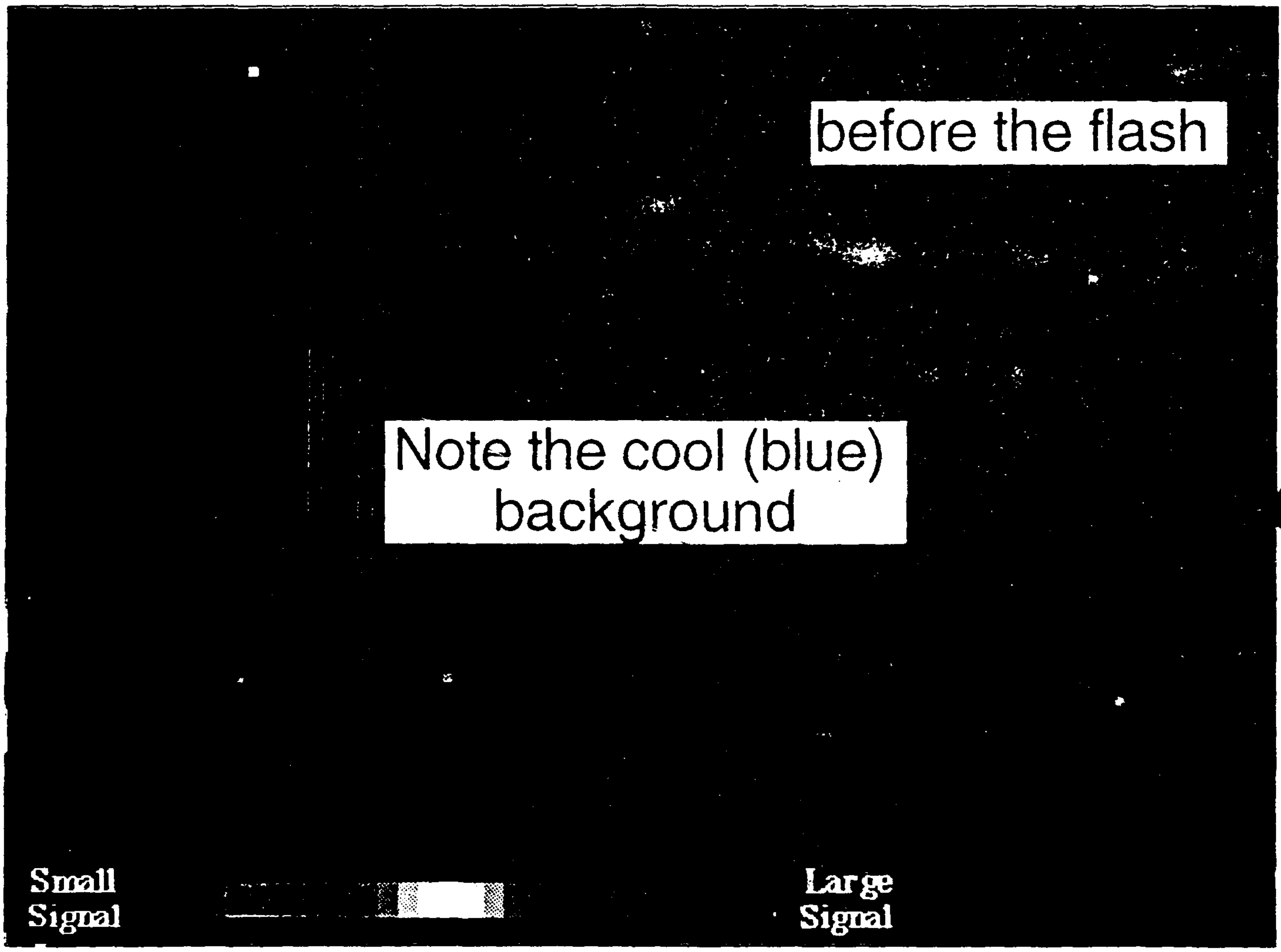
Dr. Robert L. Thomas
Wayne State University



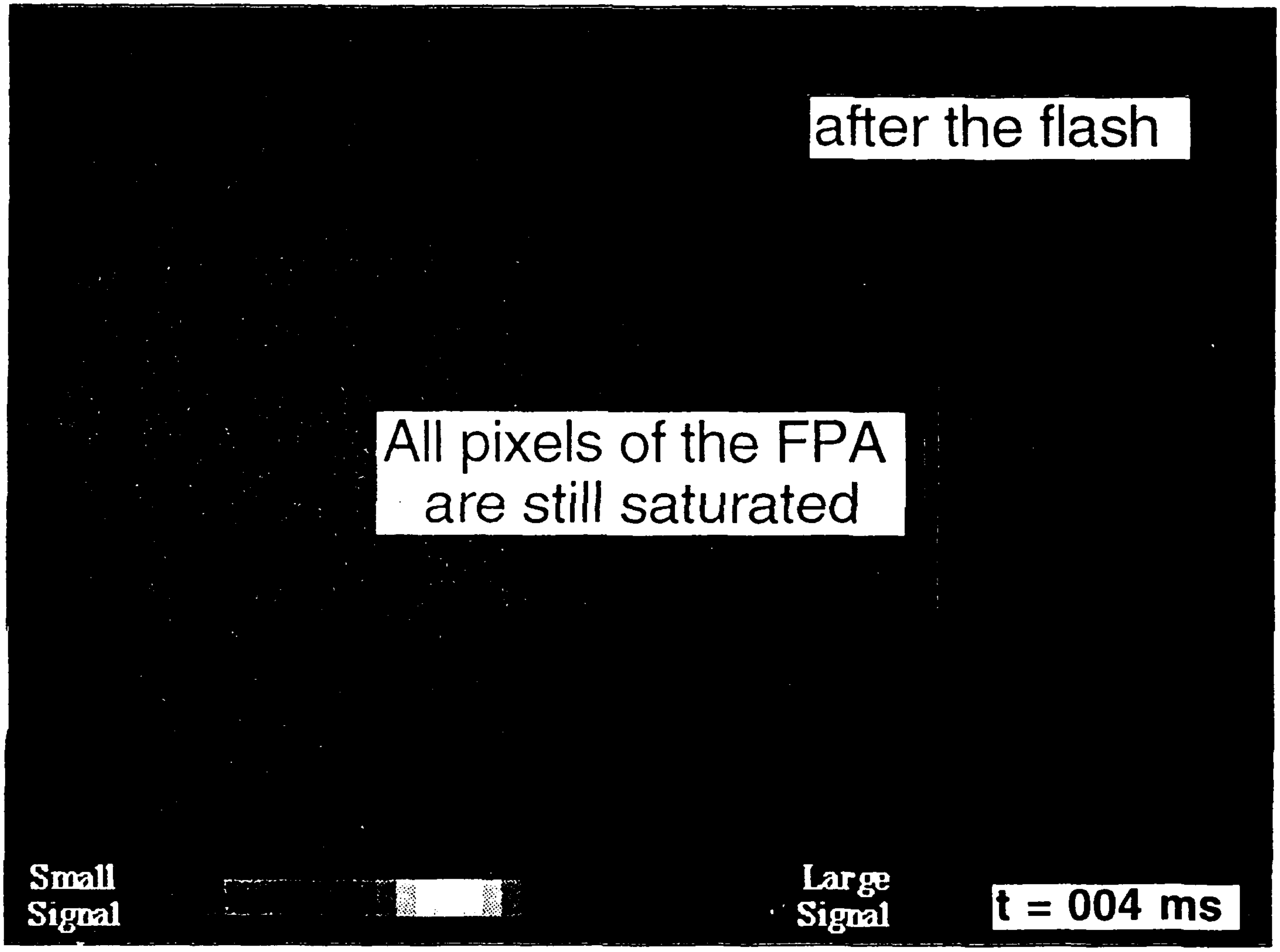
Schematic diagram of pulse-echo thermal wave imaging system.

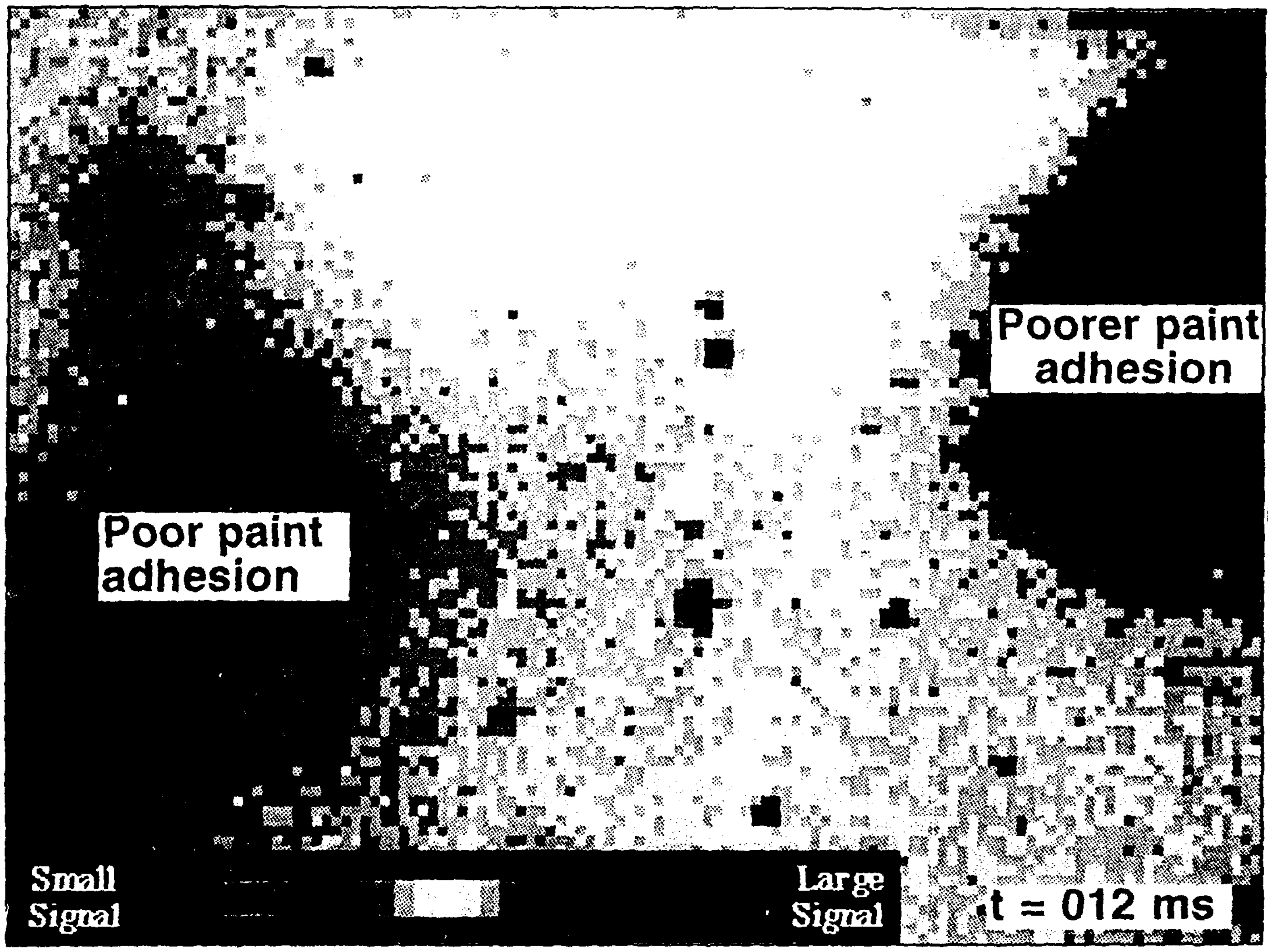


Contrast Curves: Background (T vs. t) subtracted from the (T vs. t) for the regions 1 - 6

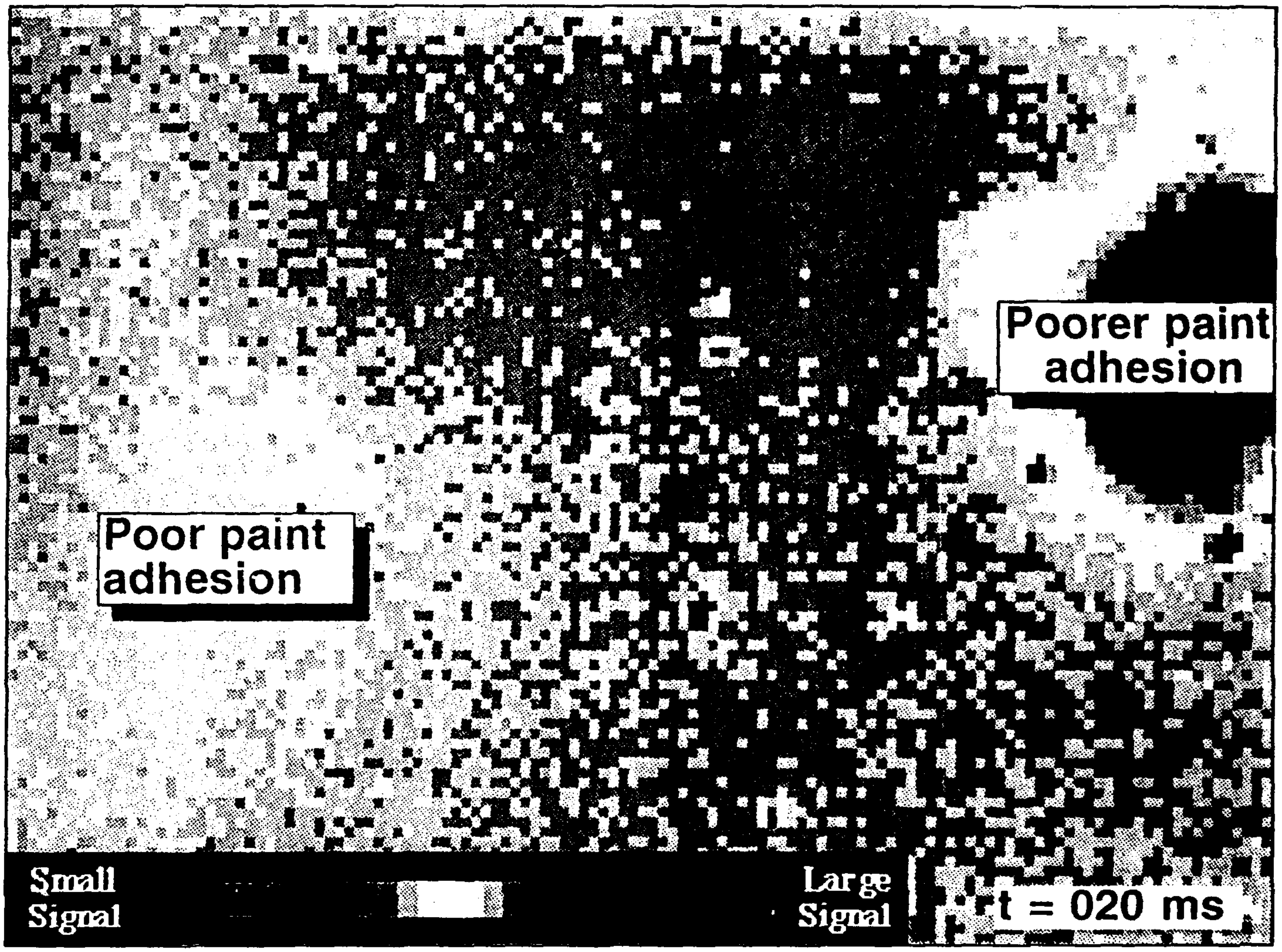


before the flash
Note the cool (blue) background
Small Signal
Large Signal

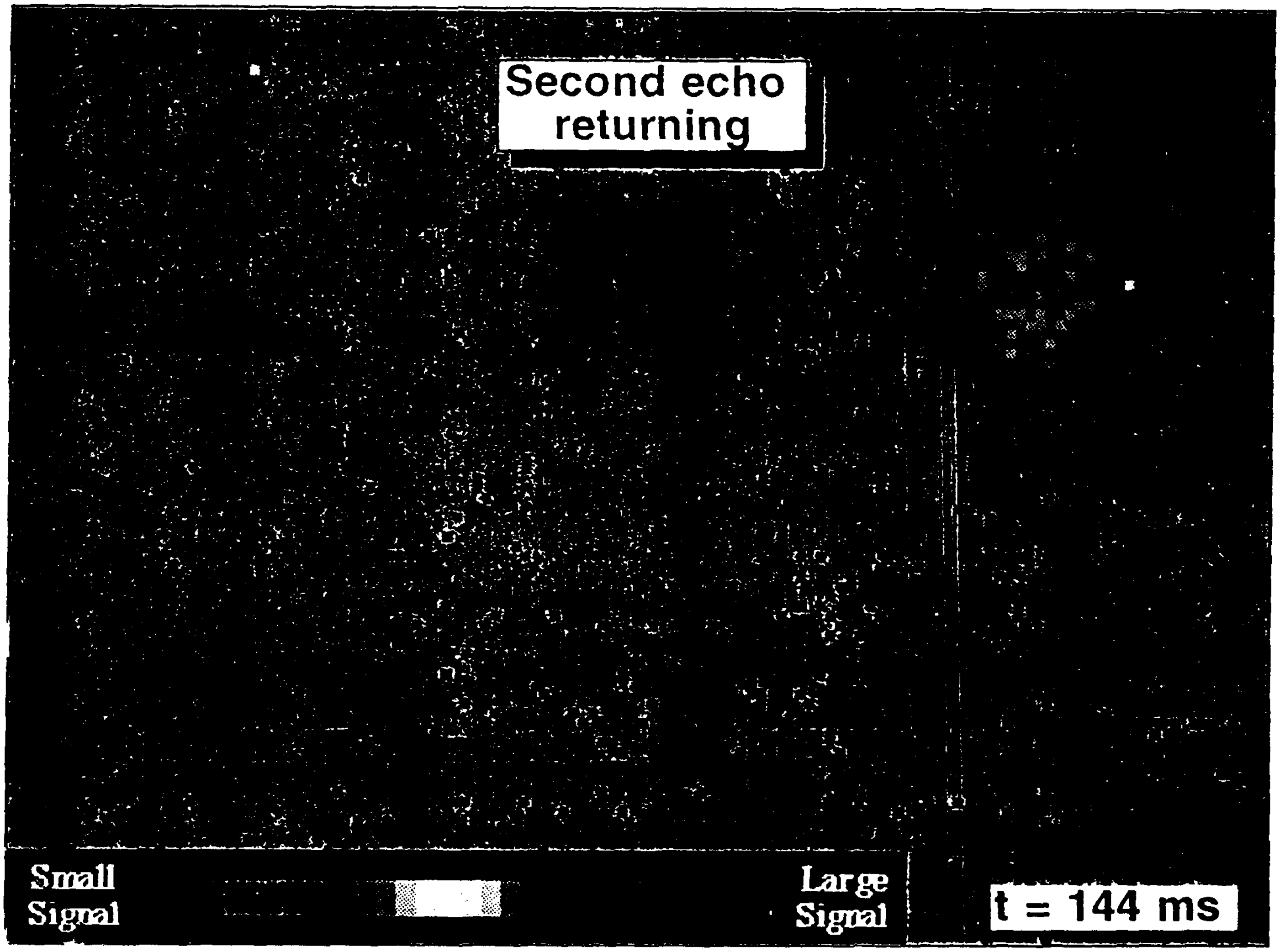

after the flash
All pixels of the FPA are still saturated
Small Signal
Large Signal
t = 004 ms

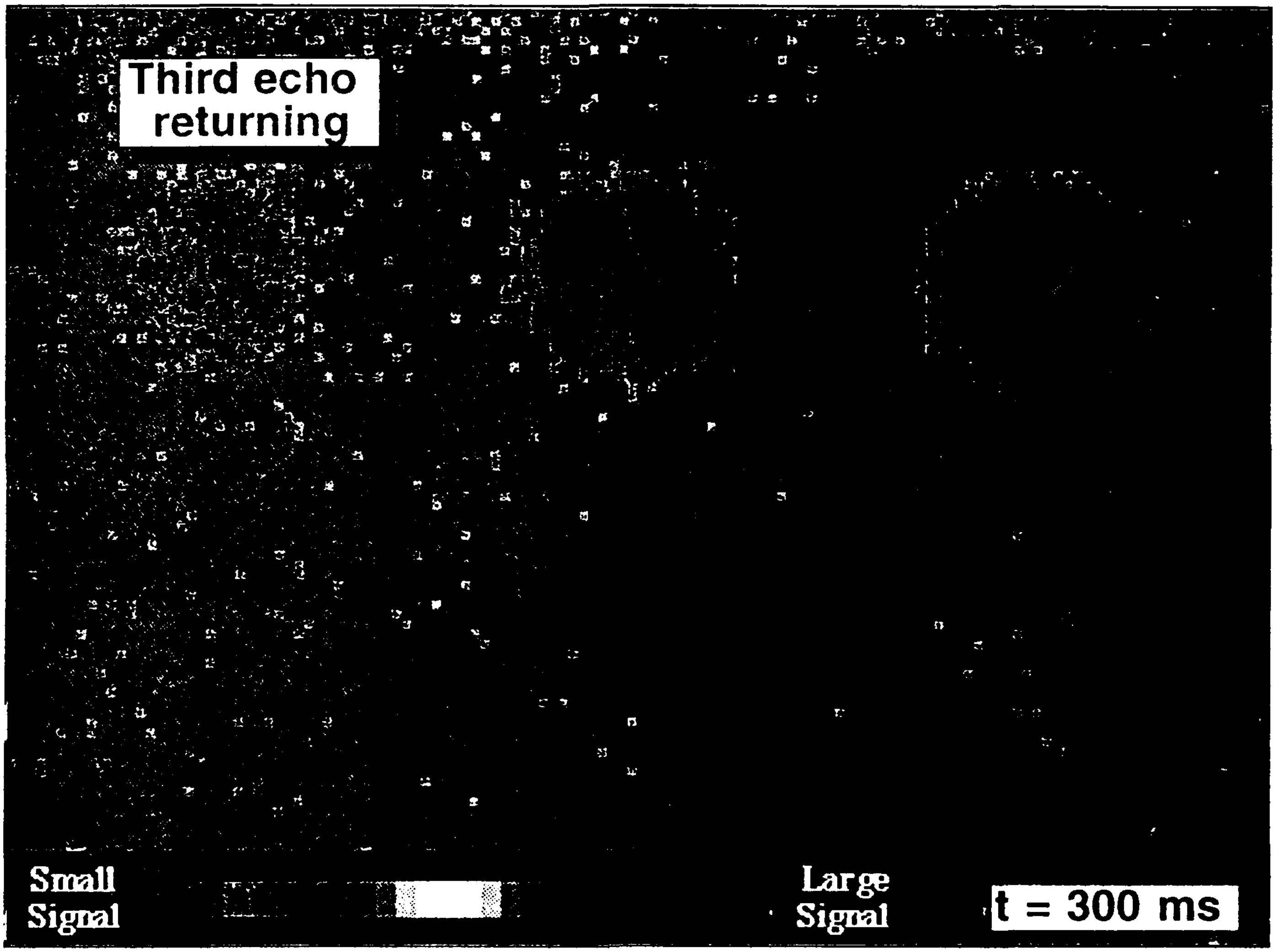


Poorer paint adhesion
Poor paint adhesion
Small Signal
Large Signal
t = 012 ms



Poorer paint adhesion
Poor paint adhesion
Small Signal
Large Signal
t = 020 ms


Second echo
returning
Small
Signal
Large
Signal
t = 144 ms


Third echo returning
Small Signal
Large Signal
t = 300 ms

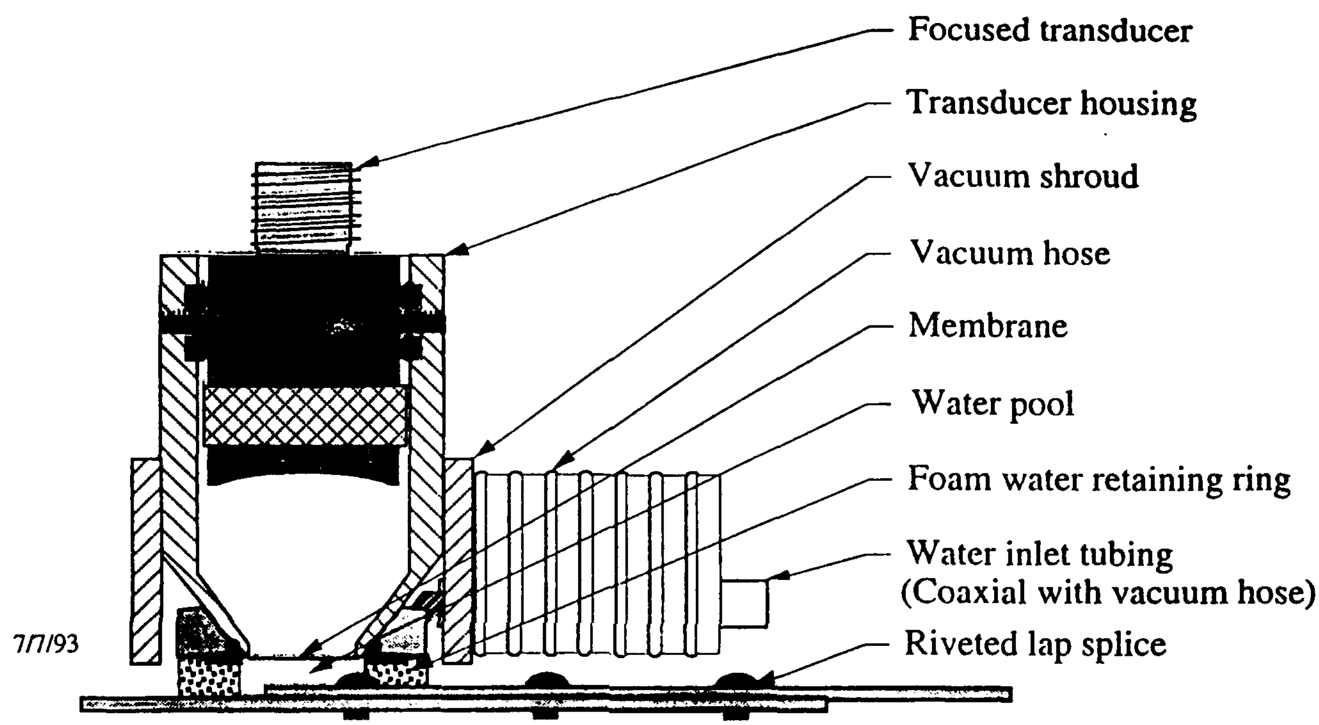
TECHNIQUES FOR FLAW DETECTION
RPI 199

Tech Area: Adhesively Bonded and
Composite Structure

Ultrasonic Characterization of Adhesive Bonds

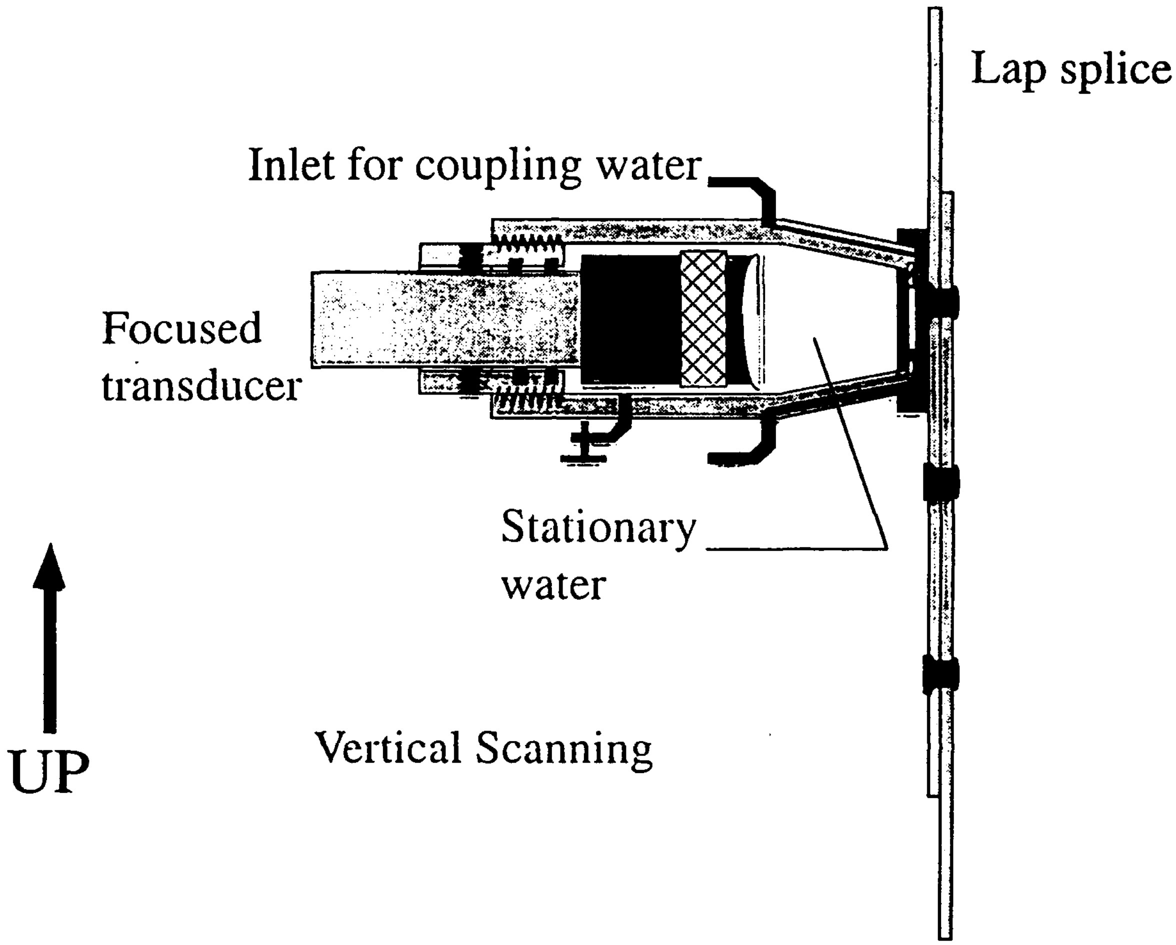
Dr. David Hsu
Iowa State University

Schematic of Dripless Bubbler

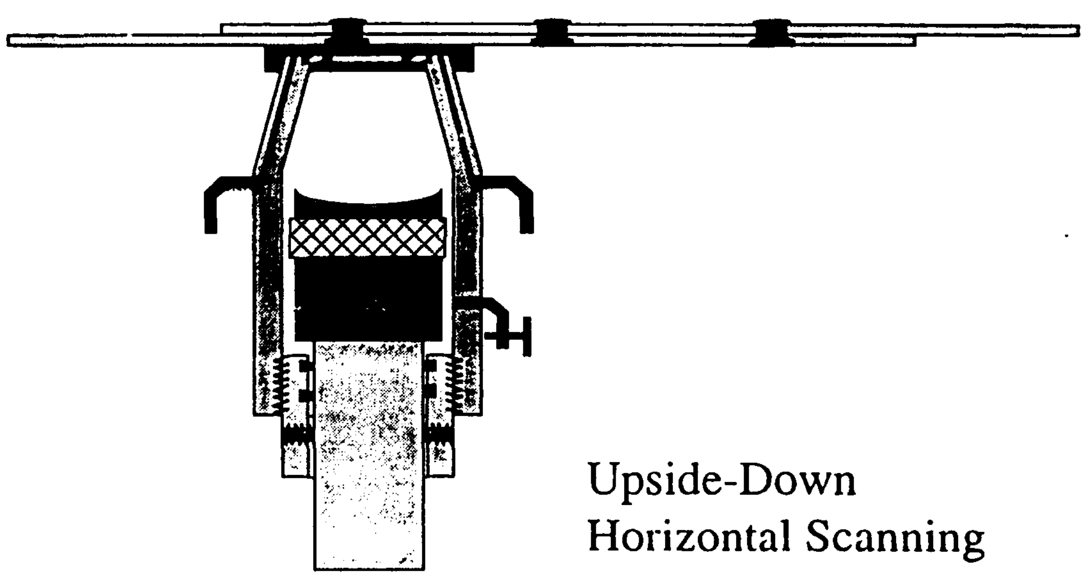


The dripless bubbler is a closed-cycle, water-coupled ultrasonic inspection method using focused transducers. It is more robust against interference fringes caused by thickness variation of bondline and paint. It is capable of scanning areas containing surface protrusions, such as button-head rivets.

Dripless Bubbler Scanning Orientations
(Vacuum attachment not shown)

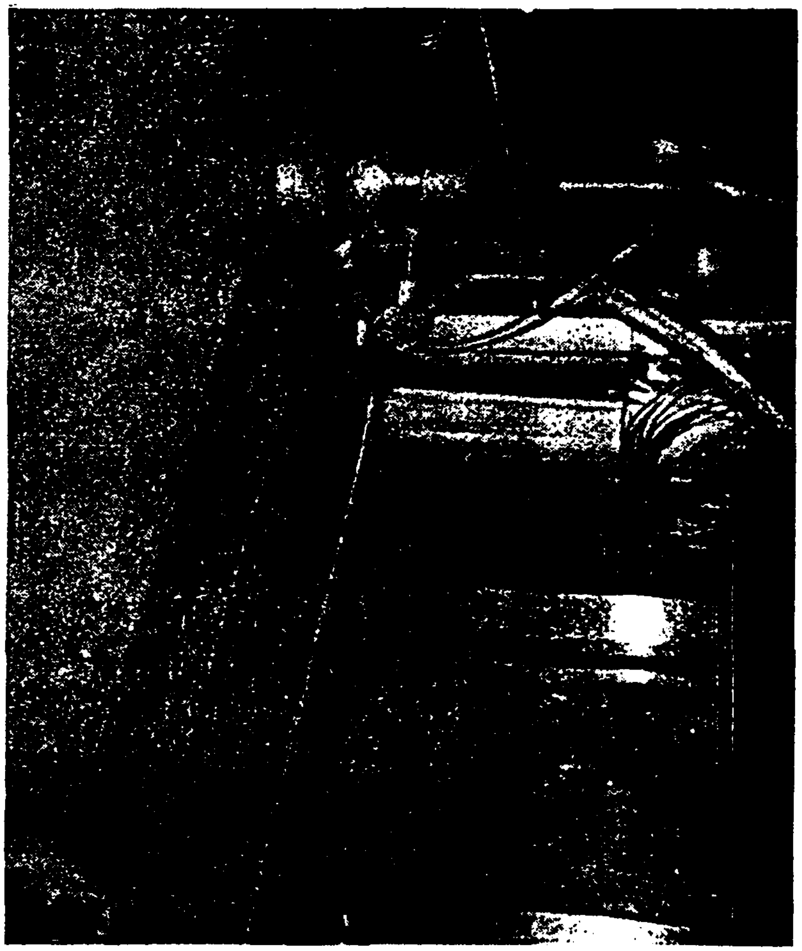


Vertical Scanning



Upside-Down Horizontal Scanning

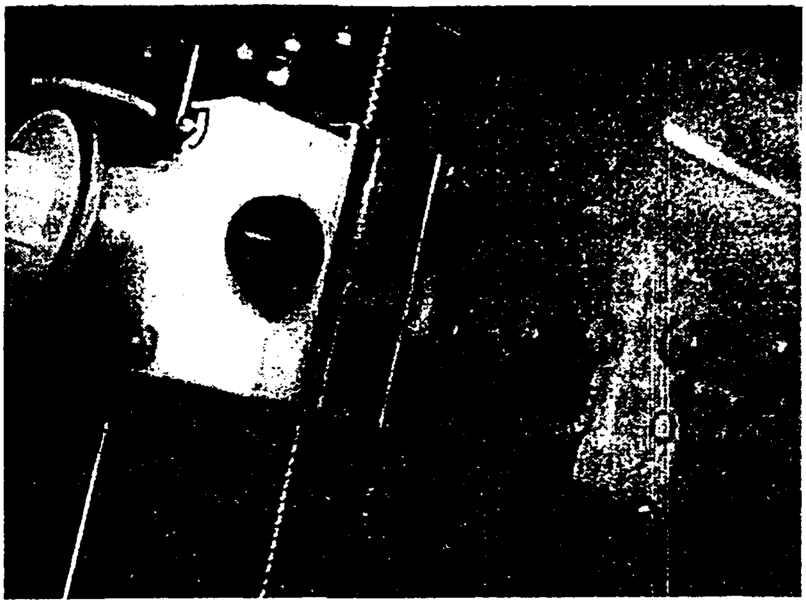
Scanning a vertical Boeing lap splice with "Dripless Bubbler" developed under FAA-CASR



The device allows focused beam ultrasonic C-scans based on amplitude and time of flight for corrosion and disbond detection.

It features a closed-cycle water pump and vacuum and can be operated on vertical or overhead surfaces. Scans can be made over surface protrusions, such as buttonhead rivets.

Field Trial on Boeing 747 at Northwest Airlines



Motorized Scanner with Dripless Bubbler
Notice top row of 1/2" dia. buttonhead rivets

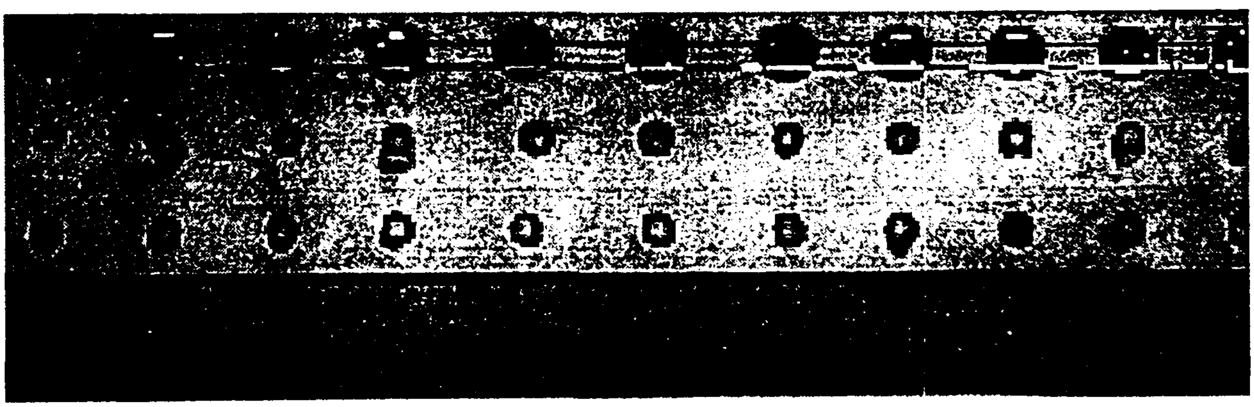
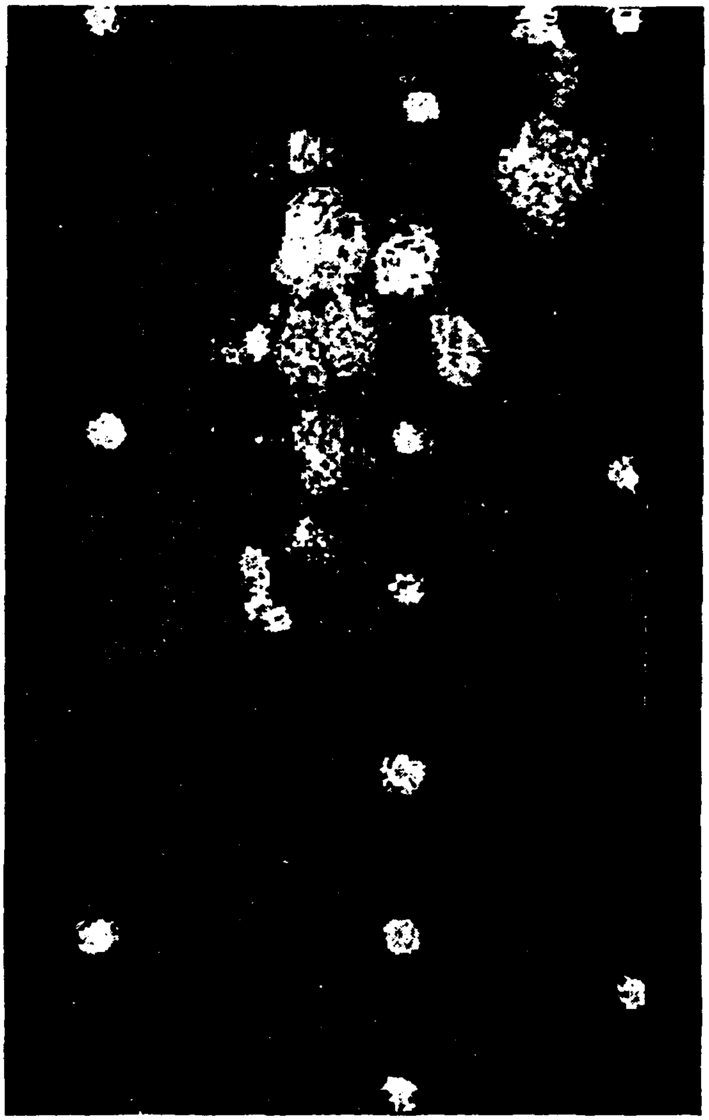


Image acquired with 1 MHz, 1" focus probe
Scan area = 12.5" x 4", step size 0.025"

Ultrasonic Time-of-Flight Scan of Corrosion in Boeing Sample VI



Pulse-echo using 15 MHz, 0.5" diam., 3" focus probe
Scan area = 5" x 8", step size = 0.025"
Circles of equal size are rivets, light gray regions are corrosion

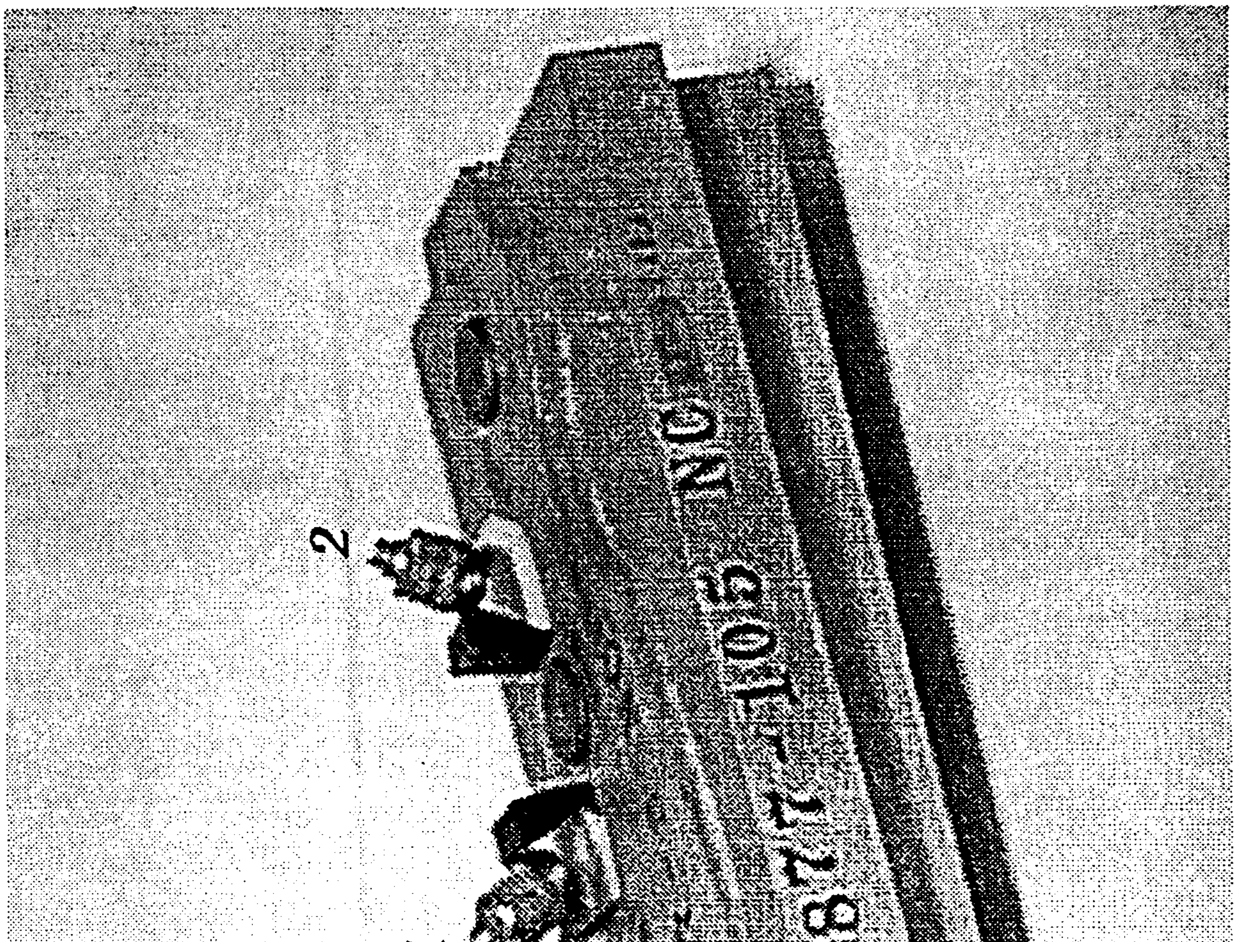
File Name BC-VI-2.CS8

NDI RELIABILITY
RPI 205

Tech Area: NDE Equipment Research

Self-Compensating Ultrasonic Instrument

Dr. J. D. Achenbach
Northwestern University


1
2

TECHNIQUES FOR FLAW DETECTION
RPI 199

Tech Area: Adhesively Bonded and Composite Structure

Optical Interferometry

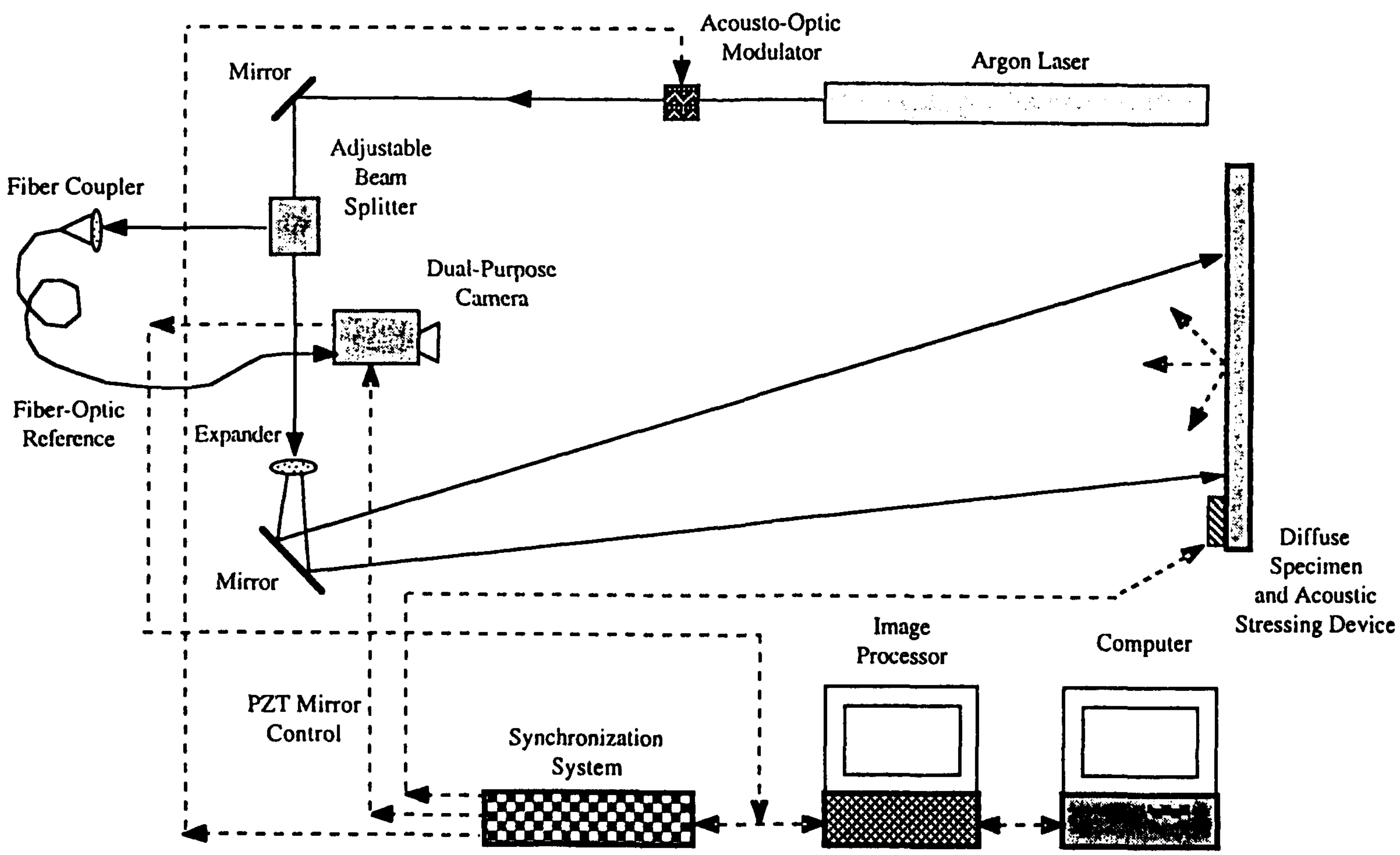
Dr. Sridhar Krishnaswamy
Northwestern University

EFFECT OF AMBIENT NOISE ON SPECKLE INTERFEROMETRY

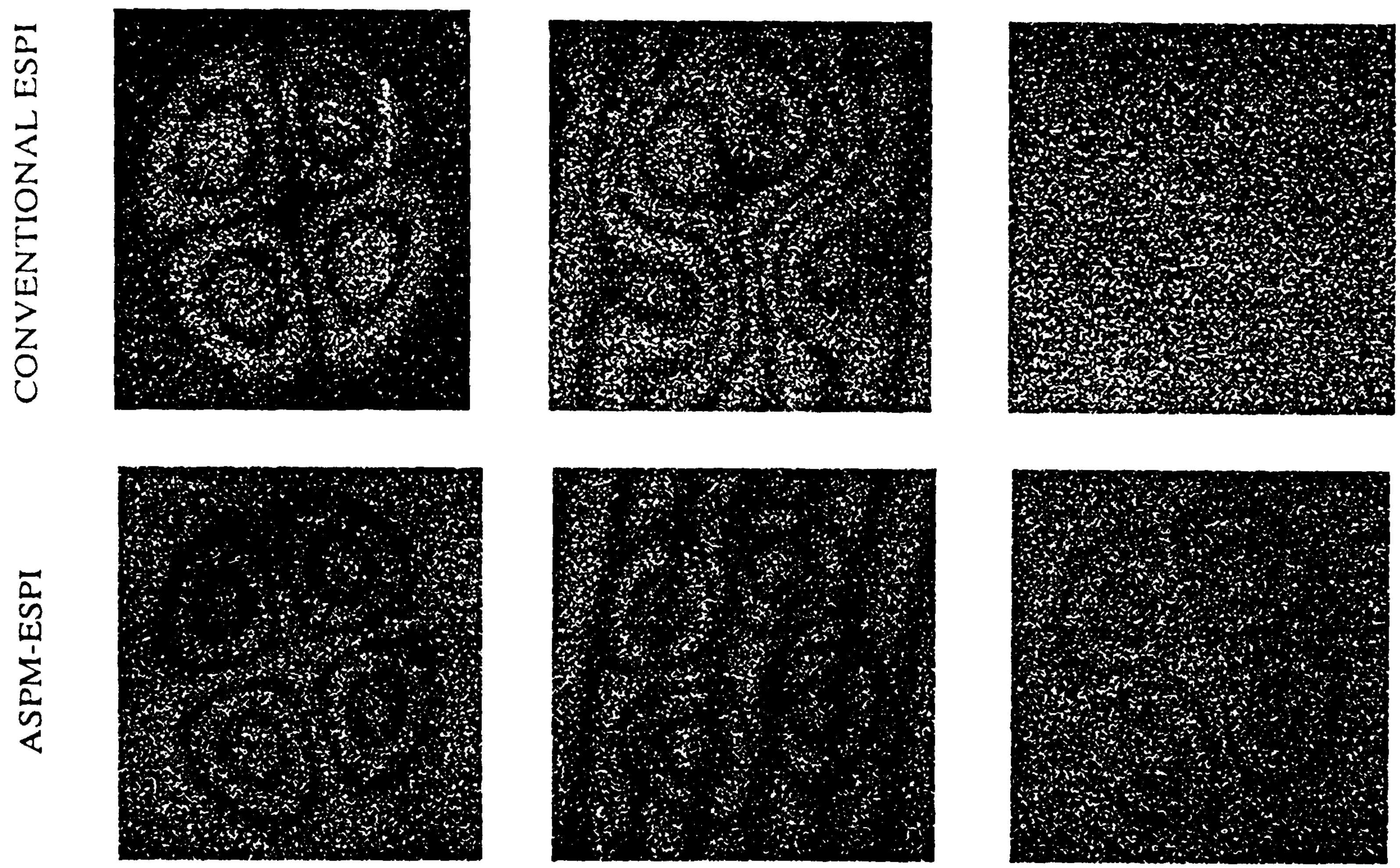
SOURCE	TYPE	EFFECT
OBJECT DRIFT (eg: settling of landing gear)	SLOW LARGE AMPLITUDE	DECORRELATION
STRUCTURAL VIBRATIONS (eg: machinery)	LOW FREQUENCY MEDIUM AMPLITUDE	DECORRELATION & PHASE SHIFTS
THERMAL NOISE (eg: air-conditioning ducts)	HIGH FREQUENCY SMALL AMPLITUDE	PHASE SHIFTS

- DECORRELATION ⇒ SIGNATURE LOSS
- PHASE SHIFTS ⇒ SIGNATURE DISTORTION

EXPERIMENTAL MINIATURE CAMERA SETUP



STUDY OF FRINGE VISIBILITY WITH TRANSLATION-INDUCED DECORRELATION



INDUSTRIAL INTERACTION

- PATENT LICENSE WITH LASER TECHNOLOGY INC.
  - MODIFYING IMAGE PROCESSING ALGORITHMS TO PERFORM REFERENCE UPDATING.
  - INCORPORATING SYNCHRONIZED STROBOSCOPIC ILLUMINATION.
  - APPLY PHASE MODULATION UTILIZING ELECTRO-OPTIC OR TRANSLATING MIRROR DEVICES.
  - SWITCHING OVER TO ESPI FROM SHEAROGRAPHY.

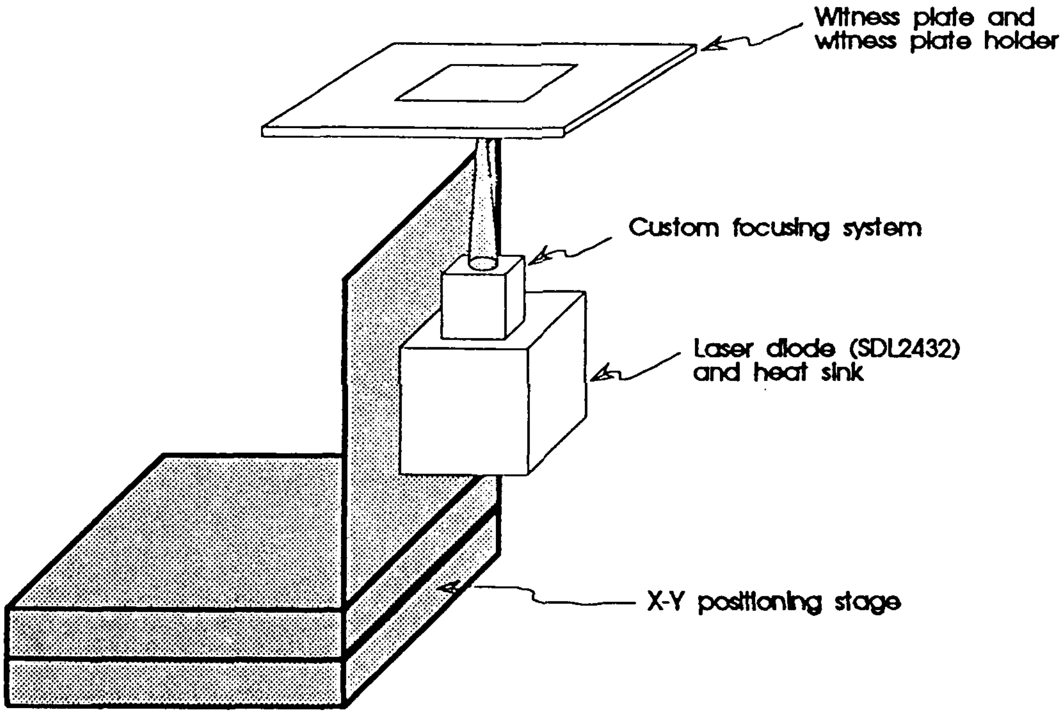
NDI RELIABILITY
RPI 205

Tech Area: NDE Equipment Research

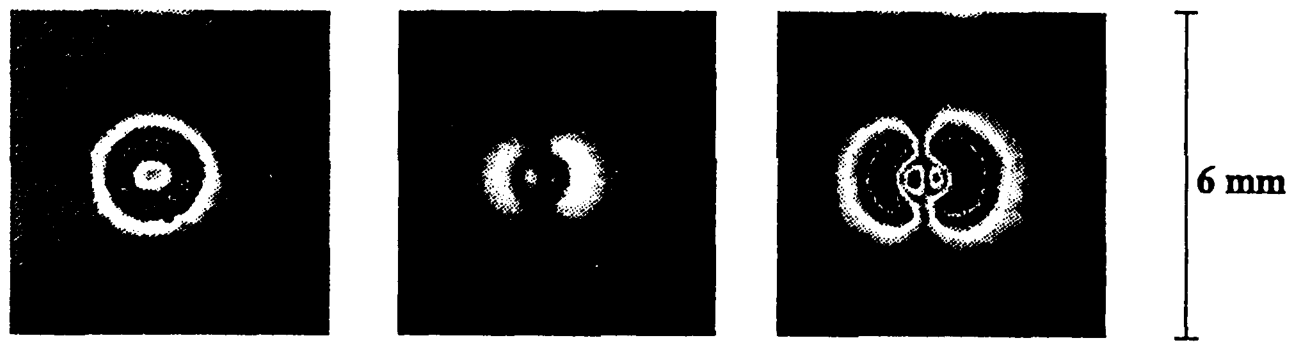
Eddy Current Probe Calibration and Standardization

John Moulder
Iowa State University

Eddy Current Probe Calibrator



2 MHz Reflection Probe



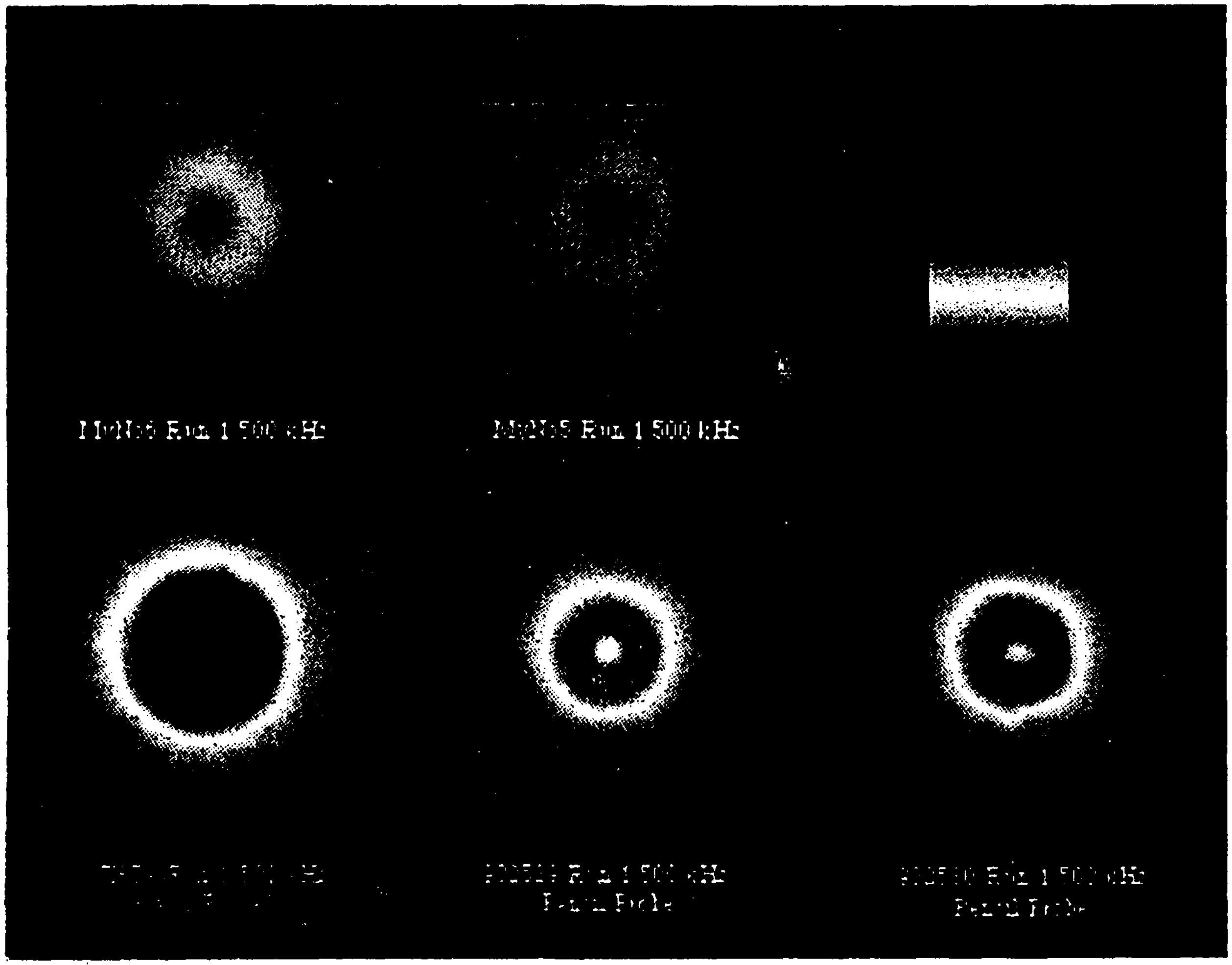
Drive Coil

Pickup Coil

Combination
(reflection probe)

Eddy Current Probe Calibrator Field Demo at NWA

Photoinductive Maps of Nominally Identical 500 kHz Absolute Probes



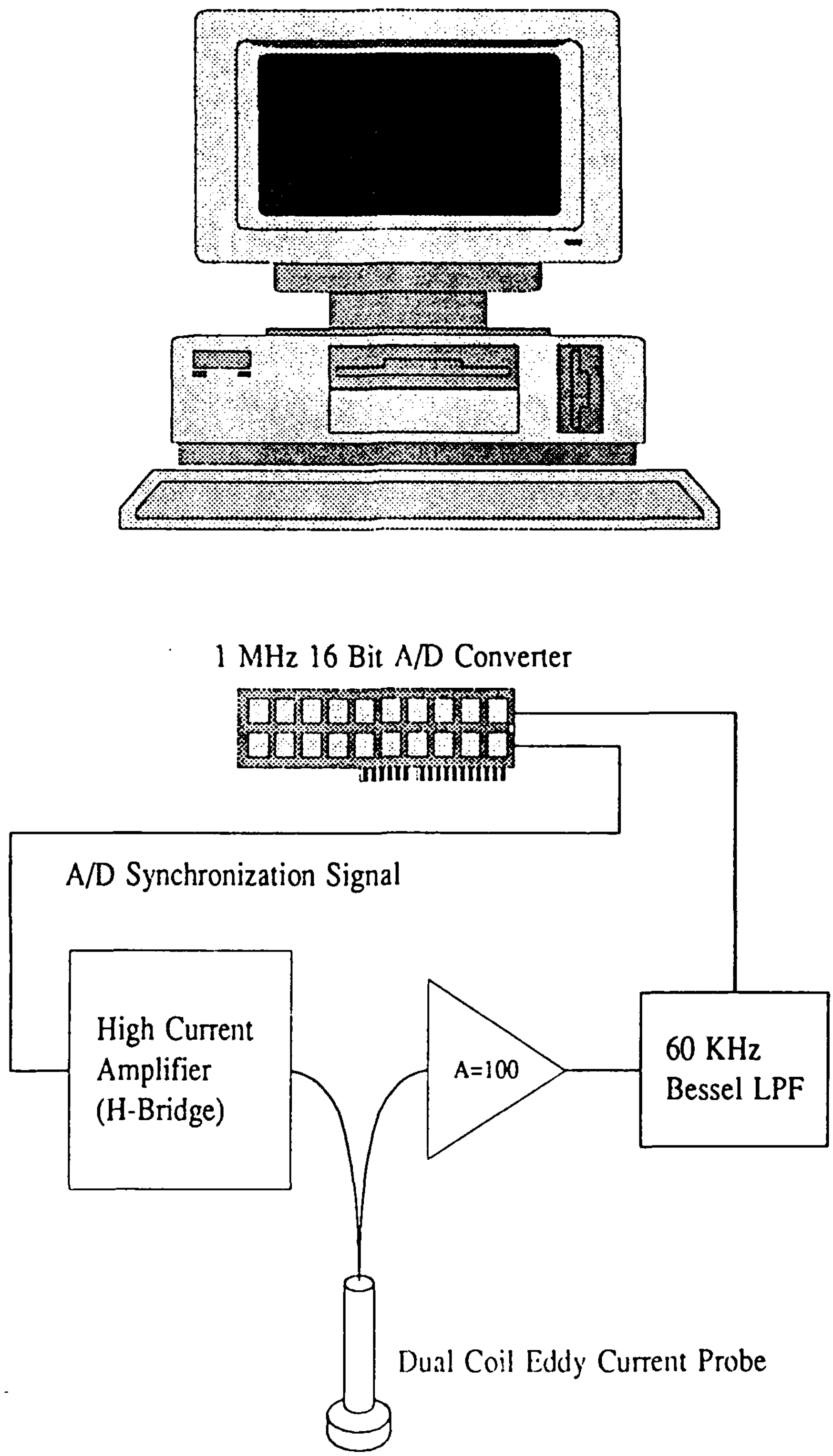
NDI RELIABILITY
RPI 205

Tech Area: NDI for Corrosion Detection

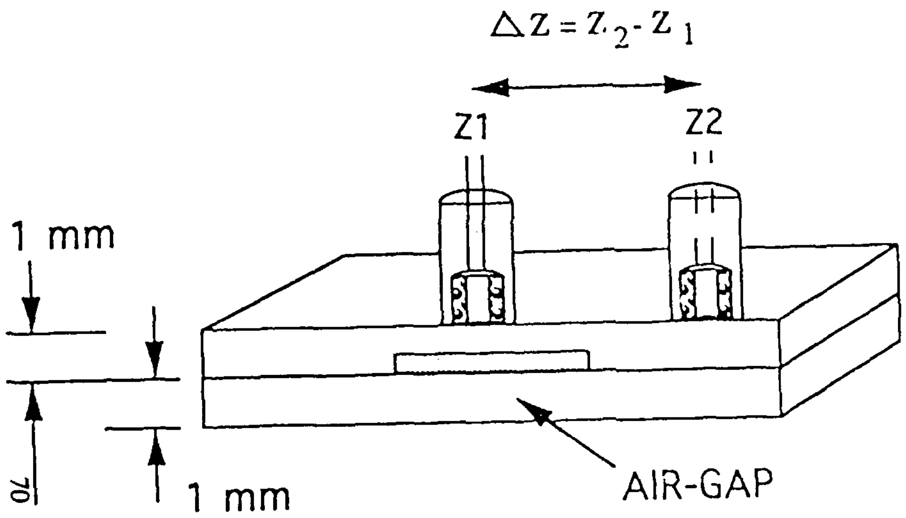
Pulsed Eddy Current for Detection of Second Layer Corrosion

John Moulder
Iowa State University

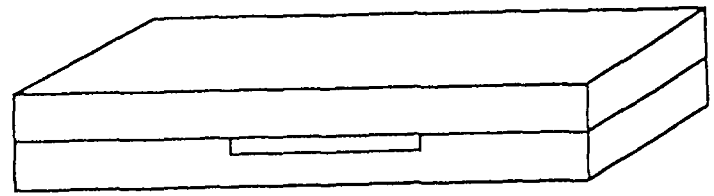
Block Diagram of 16-Bit High Speed Pulsed Eddy Current Apparatus



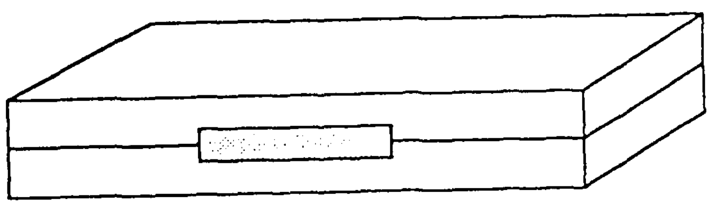
TOP PLATE THINNED



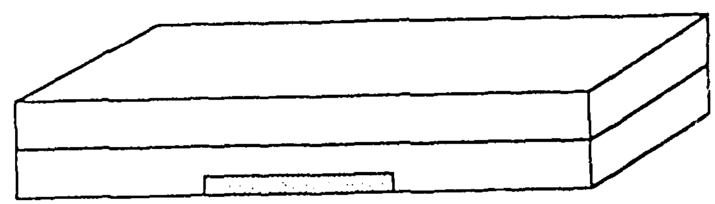
BOTTOM PLATE THINNED



BOTH PLATES THINNED



BOTTOM SURFACE THINNED



CENTER FOR NDE

Pulsed Eddy Current Theory and Experiment

Simulated Corrosion in Second Layer

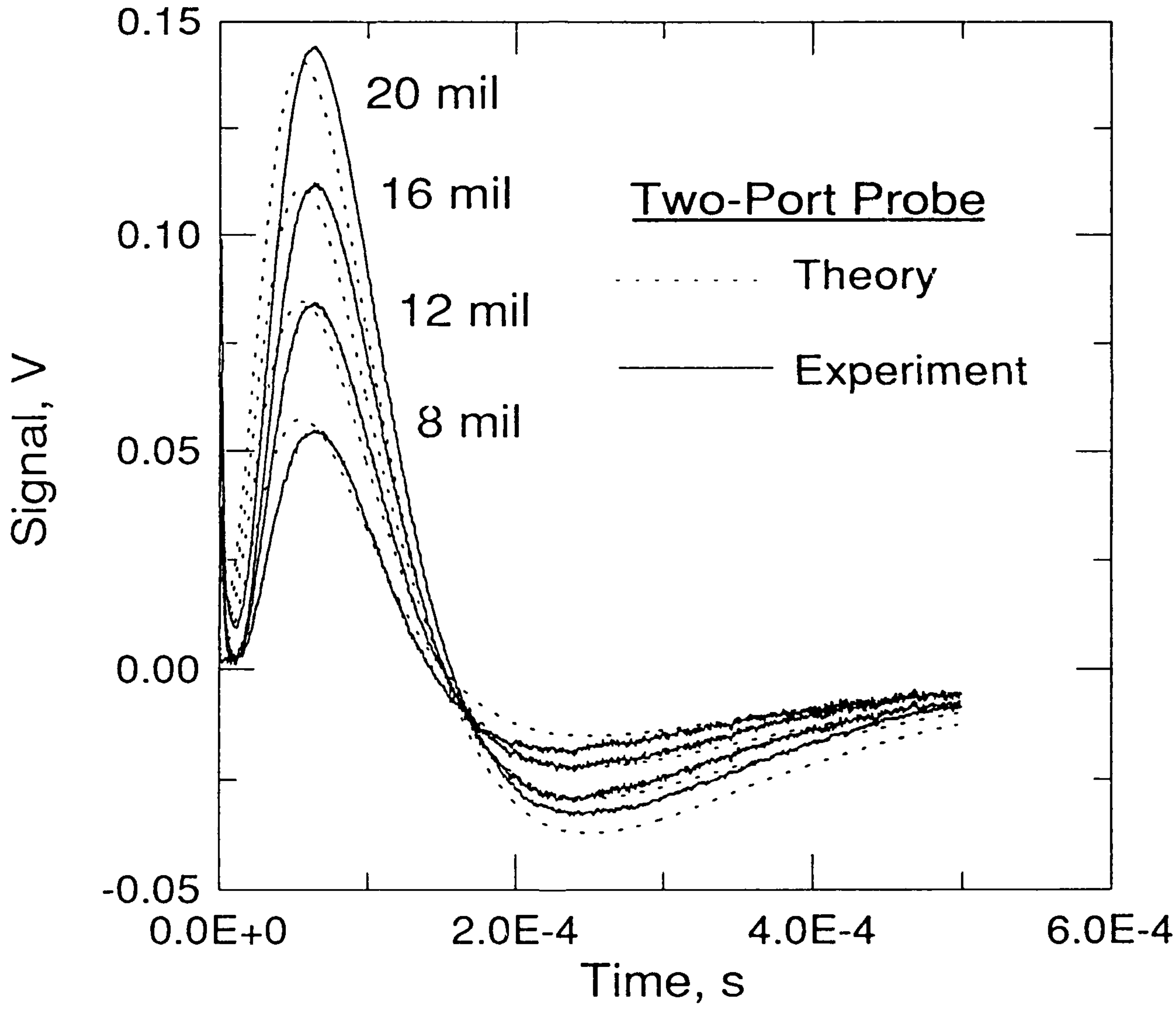
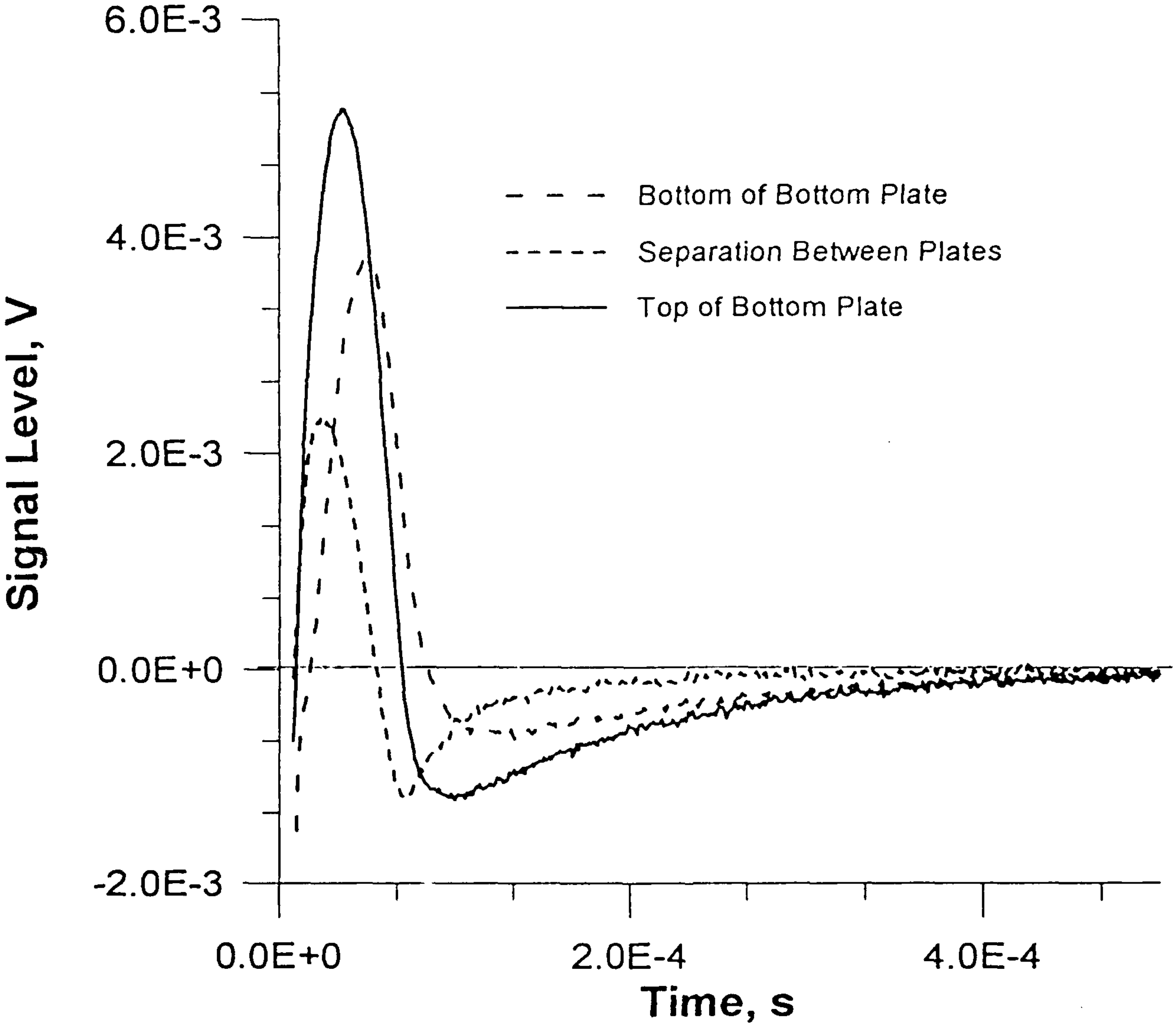
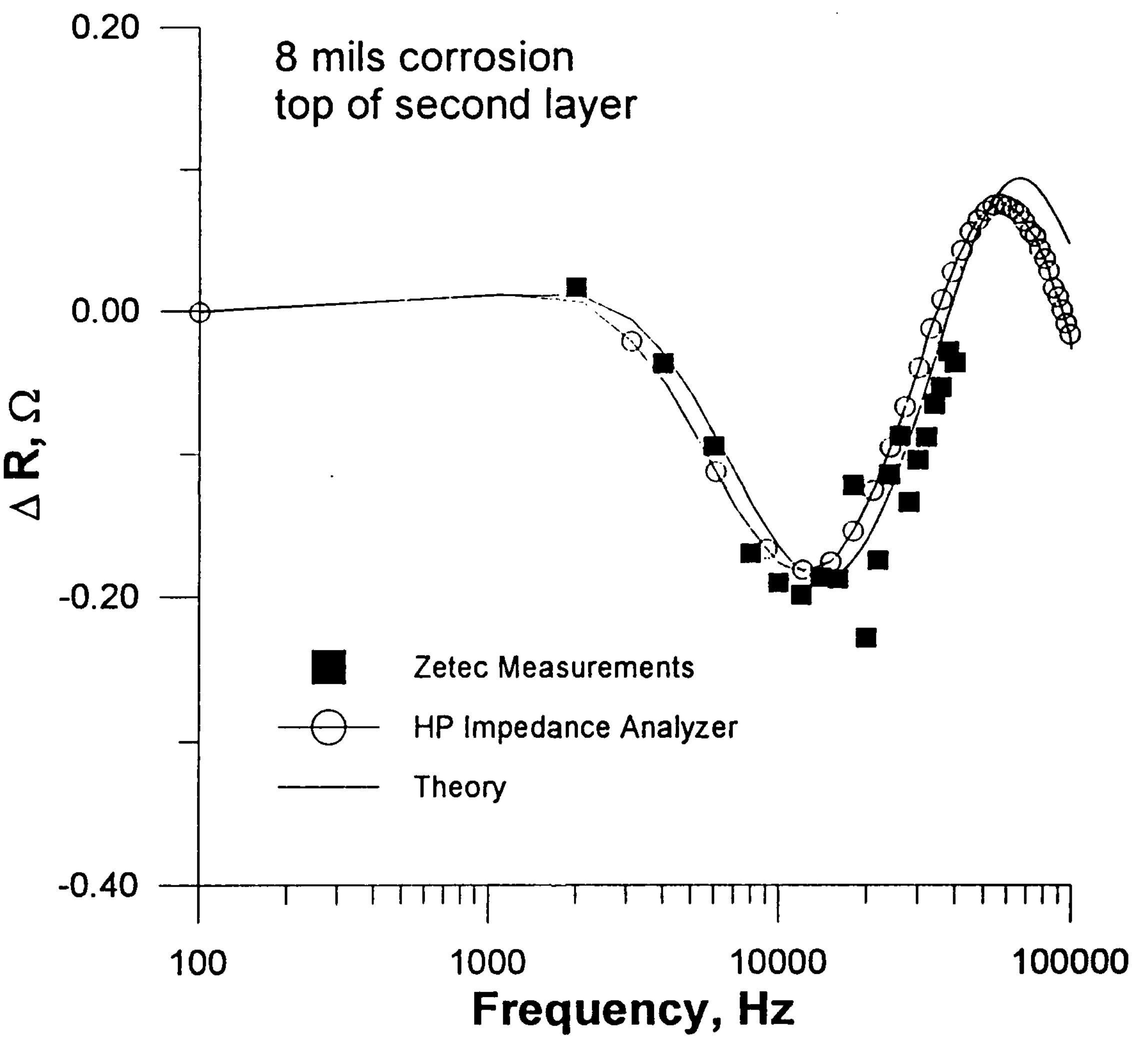


Plate Separation Compared to Simulated Corrosion (4 mils)



Zetec Eddy Current Instrument vs. HP Impedance Analyzer

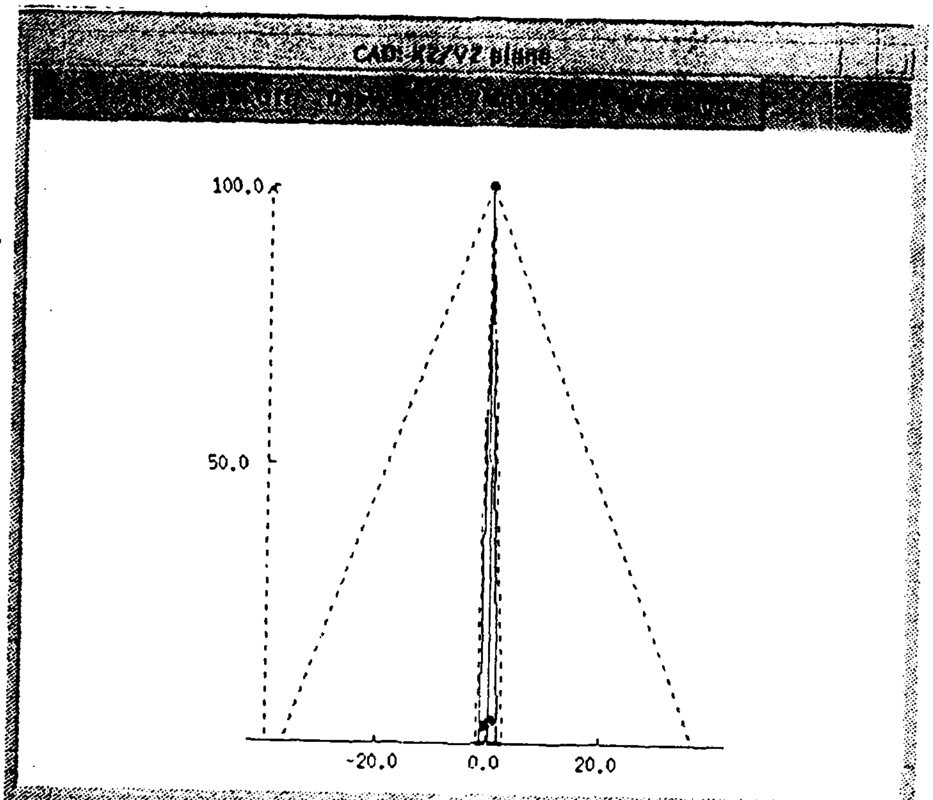


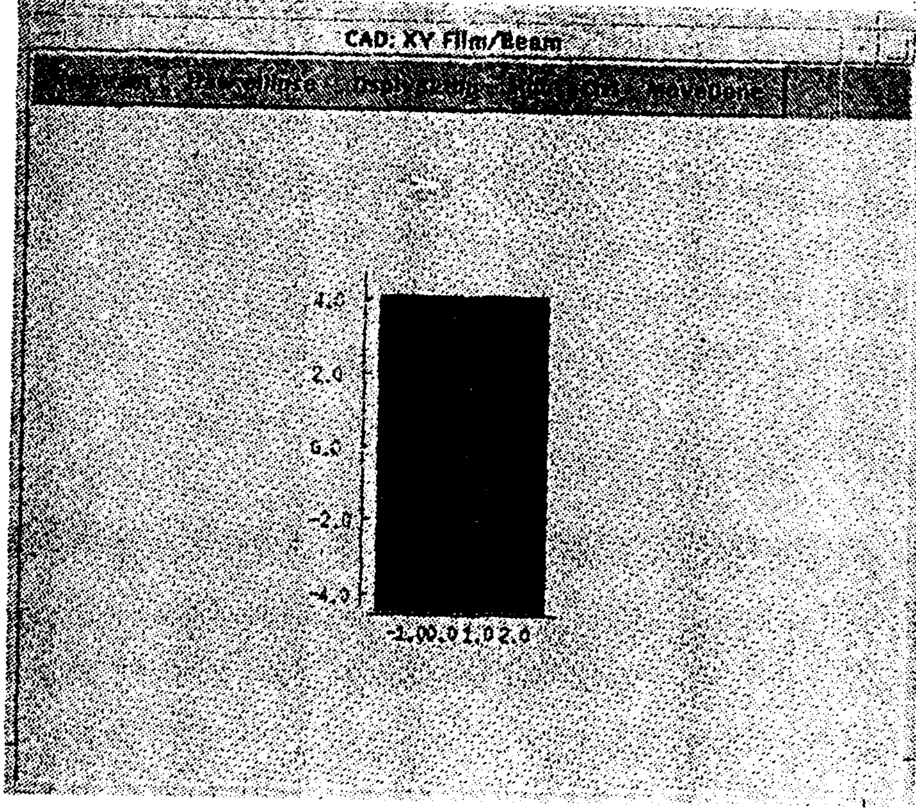
INSPECTION RELIABILITY
RPI 205

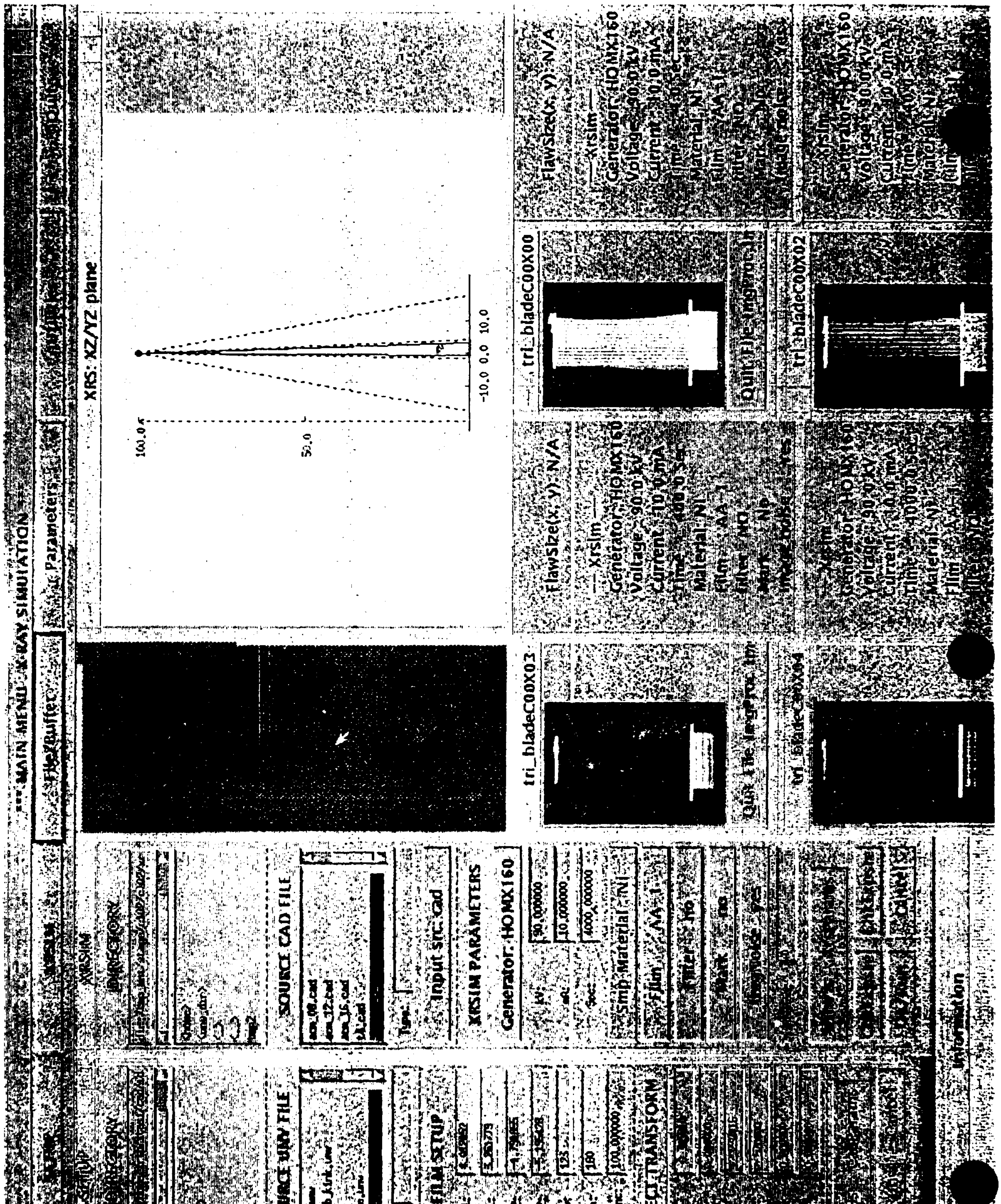
Tech Area: Inspection Simulator

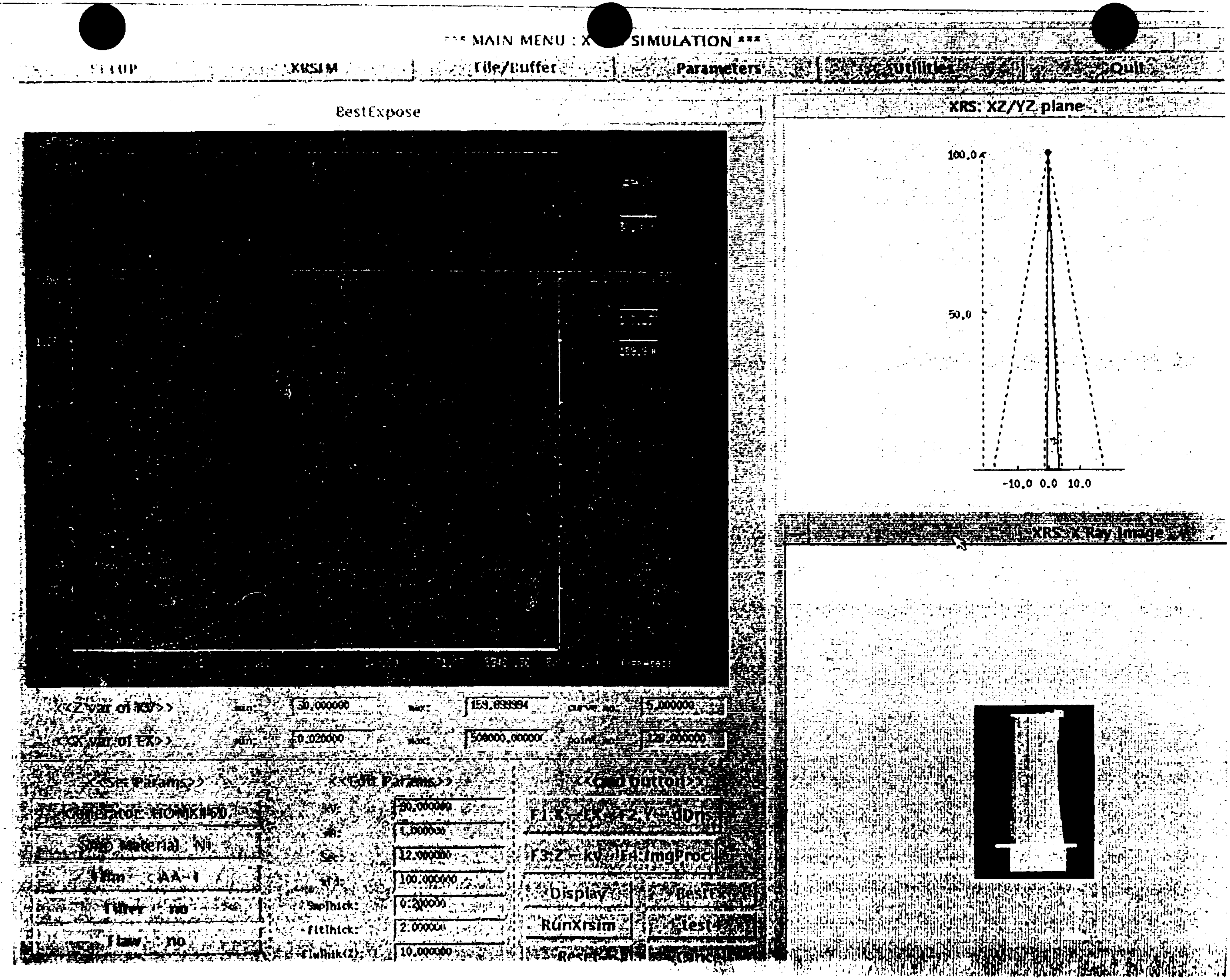
X-ray Module

Dr. Joseph Gray
Iowa State University


CAD: XZ/YZ plane
100.0
50.0
-20.0
0.0
20.0


CAD: XY Film/Beam
4.0
2.0
0.0
-2.0
-4.0
-1.00.01.02.0


MAIN MENU X-RAY SIMULATION
Parameters
XRS: XZ/YZ plane
SOURCE CAD FILE
Input src. cad
XRSIM PARAMETERS
Generator: HOMX160
FILM SETUP
OBJECT TRANSFORM
Information
tri_bladeC00X03
tri_bladeC00X00
tri_bladeC00X02
FlawSize(x, y): N/A


MAIN MENU : X SIMULATION ***
XRSIM
File/Buffer
Parameters
Utilities
Quit
BestExpose
XRS: XZ/YZ plane
100.0
50.0
-10.0 0.0 10.0
XRS: X Ray Image
<<Z var of KV>>
30.000000
159.899994
5.000000
<<X var of EX>>
0.020000
500000.000000
128.000000
<<Set Params>>
Slab Material: Ni
Filter: no
Flaw: no
<<Edit Params>>
80.000000
1.000000
12.000000
100.000000
0.200000
2.000000
10.000000
F3:Z←kv F4:ImgProc
Display
RunXrsim

NDI AUTOMATION AND ROBOTICS
RPI 200

Tech Area: Evaluation of Advanced NDE Concepts

Image Processing for Radiographic Inspection

Dr. Richard Wallingford
Iowa State University

FAA Center for Aviation Systems Reliability

Task - Image Processing for Radiographic Inspection

<u>Status Last Year</u>:

1. Defined target problem after visit to NWA at Atlanta, Georgia
   - Real-time x-ray image enhancement in burner can insepction and other engine components

2. Defined the required capabilities and specifications fo a real-time x-ray image processor
   - Must improve inspection sensitivity and POD in *real-time*
   - Must be low-cost and easy to use
   - Must be integrable with existing airline inspection systems (add-on)

NDI Automation
and Robotics
RPI 200

FAA Center for Aviation Systems Reliability

Current Status:

1. Working prototype has been assembled and successfully demonstrated on a variety of inspections:
   - Improved detectability of burner can cracking
   - Detectability of fatigue cracks under non-optimal orientation
   - Detection of porosity

2. Positive feedback from airlines (Northwest and Delta) at recent in-house demonstration
   - Beta site evaluation planned for next few months at NWA in real-time inspection facility in Atlanta, Georgia

3. System repeatedly demonstrating a POD improvement from 0% to 100% in several detection studies. System sensitivity improved from 4% (unprocessed) to <1% (processed).

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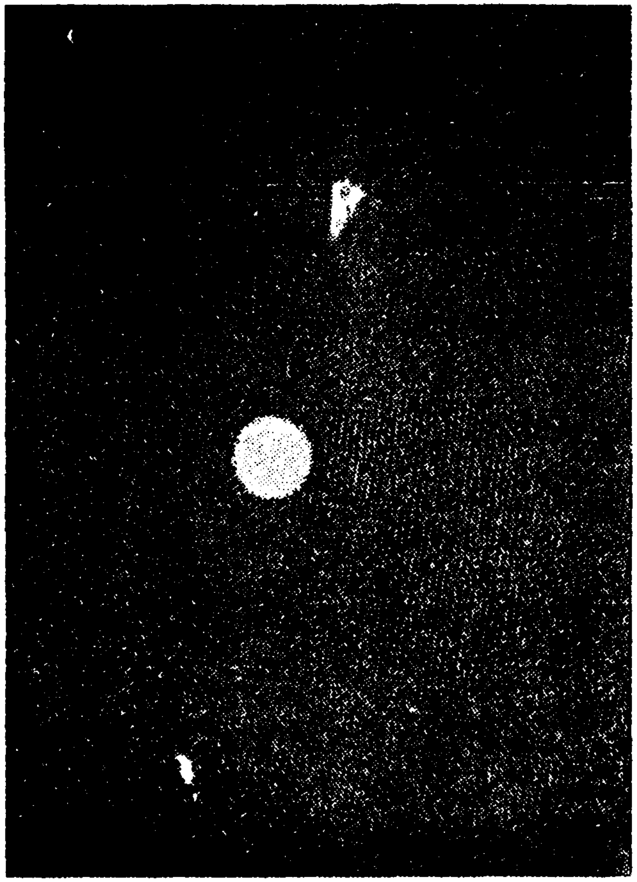
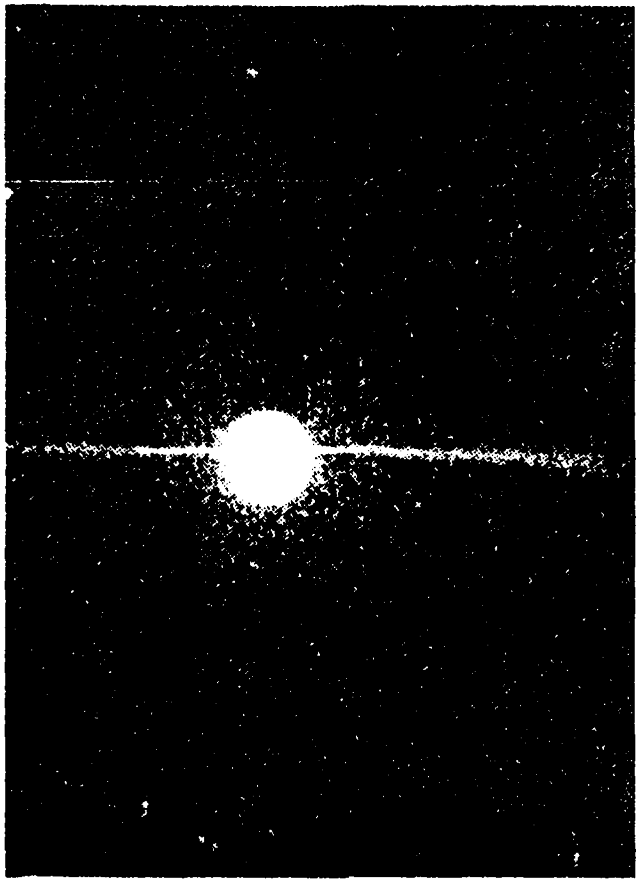




Unprocessed

RT Processed

Typical Processing Result on Fatigue Crack Detection

NDI RELIABILITY
RPI 205

Tech Area: NDI For Corrosion Detection

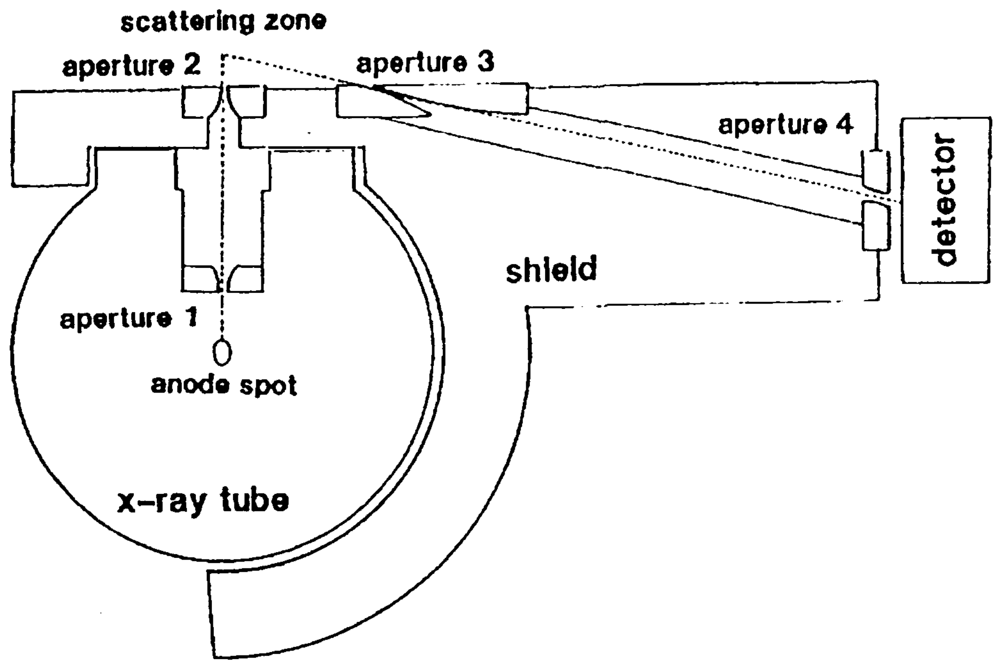
Radiographic Methods for Corrosion Detection

Dr. Jan Achenbach
Northwesten University

FEATURES OF COMPTON X-RAY BACKSCATTER DEPTH PROFILOMETRY

- Gives a cross-sectional view of aircraft sheet metal joints.
- Allows measurement and identification of sub-surface layers.
- 1/1000 inch measurement accuracy.
- Generates very little ambient x-radiation.
- No evacuations--Does not interfere with most hangar activity.
- Self-propelled. Scaffolding and stands are not needed.
- Data are digital files -- easily stored and transmitted via Internet.

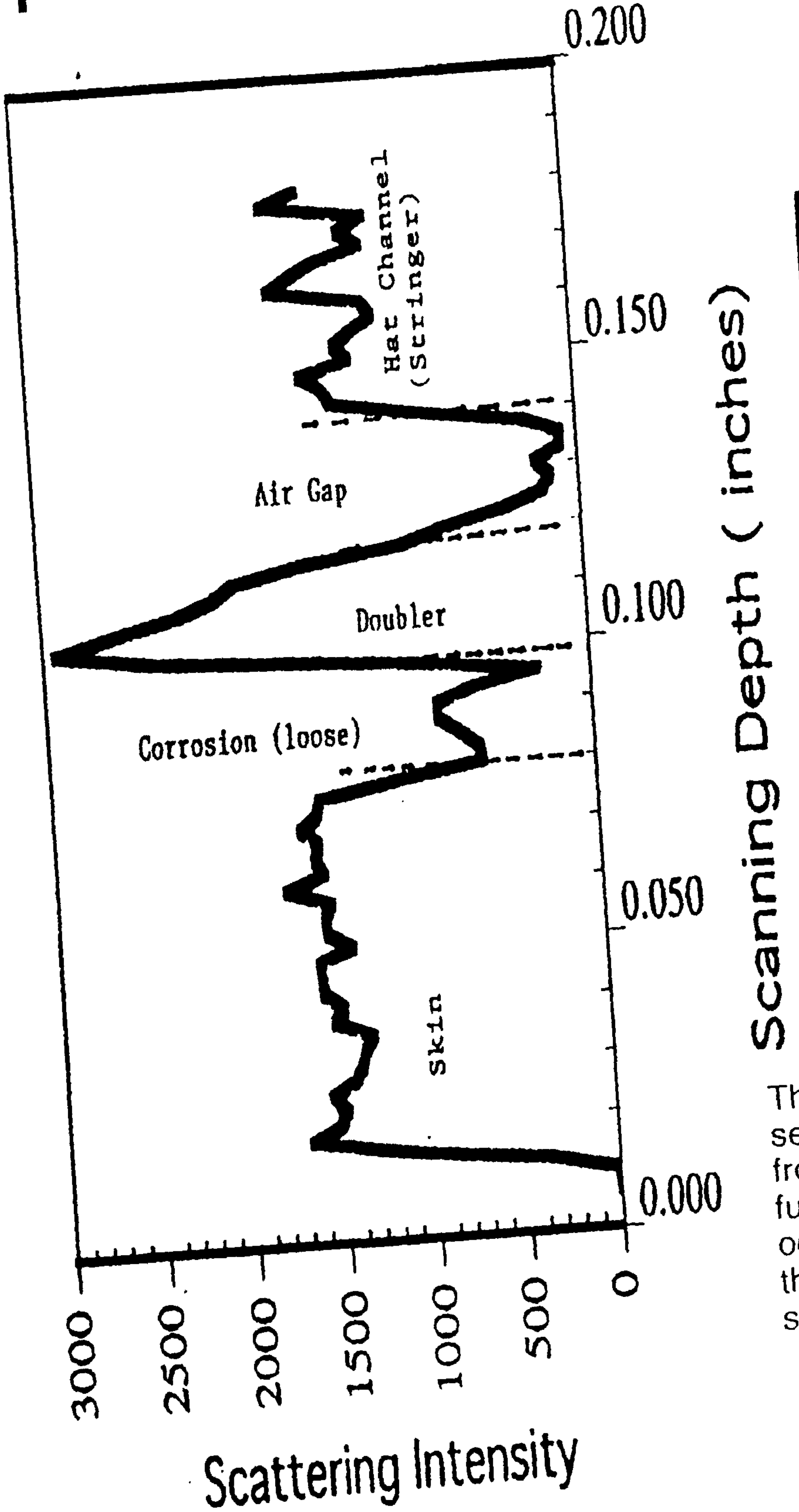
Depth Profiling Apparatus

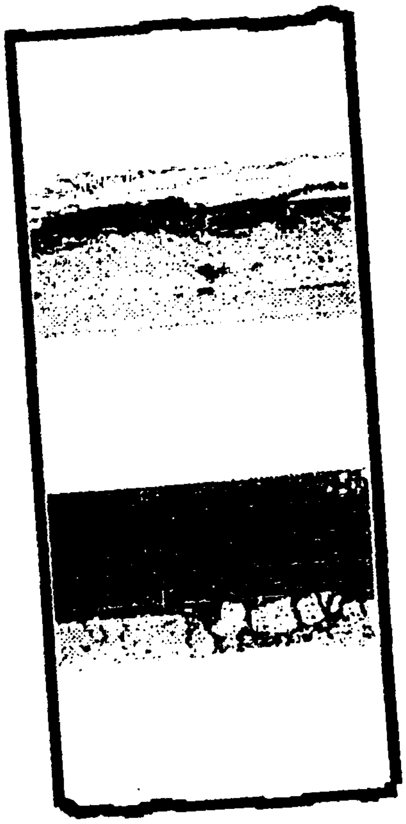


The depth profiling camera consists of four sets of apertures. The first two sets form the beam into a pencil with a narrow rectangular cross-section. The second two sets select a limited thickness region from which backscattered photons reach the detector. The intersection of the incident and backscattered beam paths form a scattering zone or focal region. Sweeping this region through the material to be examined allows visualization of the electron density of the material along the path. In depth profiling, the path is normal to the surface and the result is similar to drilling and examining a core section taken at that point.

The scattering zone is nearly Gaussian in the depth direction with a "standard deviation" size parameter of 0.0013 inches.
Limiting (10% MTF) resolution is 10 lp/mm.

Depth Profiling vs. Core Sectioning





The scan on the left and the core section on the right were both taken from the same area on a corroded fuselage. Some displacements occurred as a result of drilling. Note the exfoliative corrosion of the stringer (at the top of the picture).

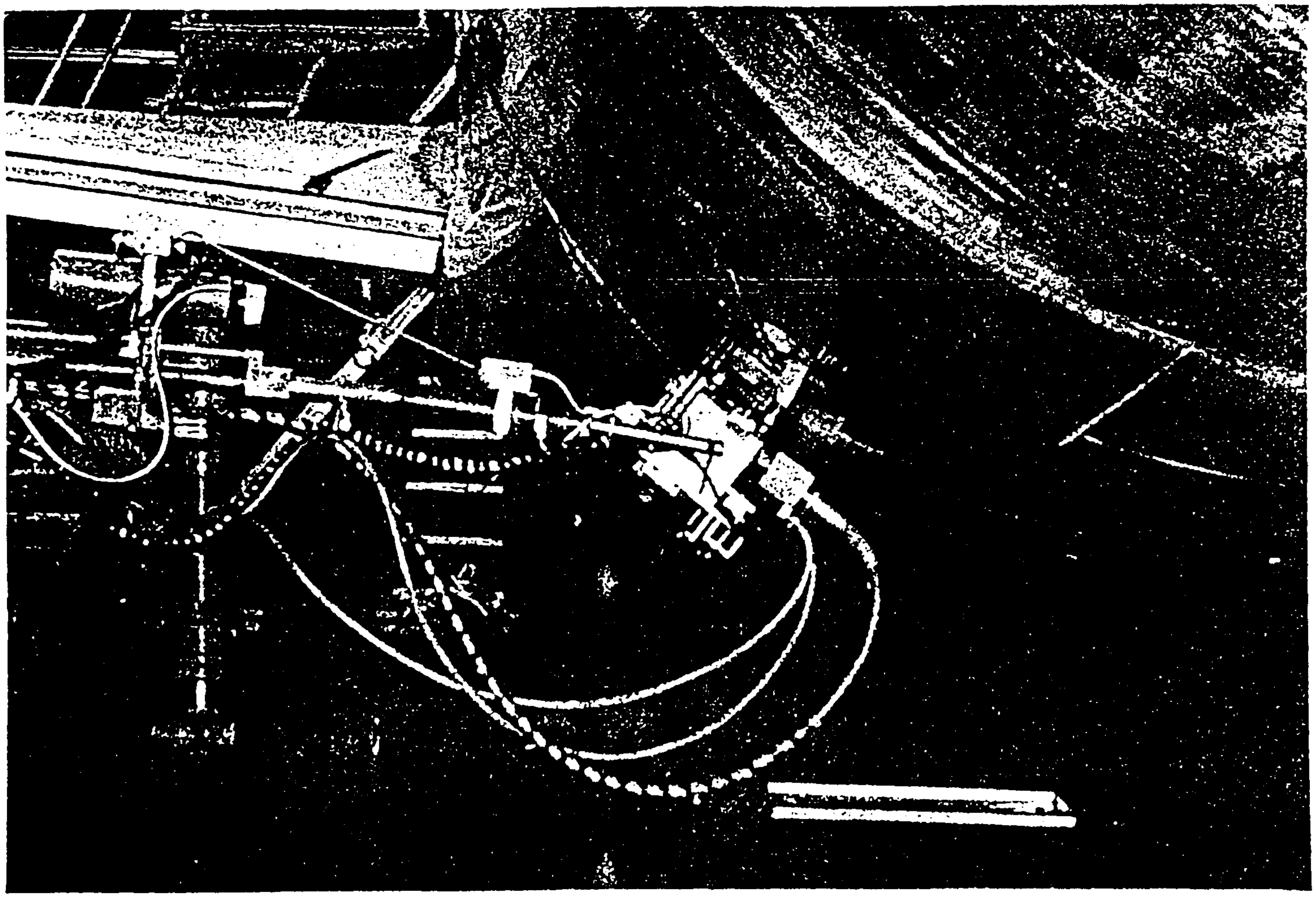


Fig. 4 X-Ray BDP Scan in place underneath an aircraft for scanning the belly section.

FAA-CASR Technology Transfer Plan

Dale Chimenti
Iowa State University

Robert Thomas
Wayne State University

Jan Achenbach
Northwestern University

FAA-CASR Technology Transfer Plan

- ▶Neural net wheel inspection beta site at NWA (ISU)
- ▶ESPI licensed to Laser Technology Inc (NWU)
- ▶Realtime x-ray image enhancement beta site at NWA, DL (ISU)

- Self-compensating probe for DC-9 tee-cap (NWU)
- Dripless bubbler for lap-splice inspections (ISU)
- Self-compensating probe for DC-10 vert stablzr (NWU)
- Thermal wave imaging system devlopment (WSU)
- X-ray backscatter depth profilometer, AANC demo (NWU)
- Advanced, wide dynamic range x-ray film densitometer (ISU)
- X-ray simulator multiple beta site and AANC demo (ISU)
- Precision eddy current calibrator multiple beta site and POD study (ISU)

Dripless Bubbler Overview

NEED

- Airline survey shows interest in reliable, rapid, large-area U/S scan capability (UA, AA, NW, DL, USA)
  - Disbonds
  - Corrosion
  - Repair/thinning discrimination
  - Over protruding, buttonhead rivets, lap-splice edges
  - Compatible with hangar maintenance environment

RESPONSE

- Unique, captured-water volume U/S probe and detection method
  - Rapid scan capability
  - Reliable, consistent water coupling
  - Scans over protruding rivets
  - No uncontained water
  - Interchangeable, focused transducers
  - Immersion techniques implementable on A-C structure

Dripless Bubbler Technical Approach

<u>GOALS FOR TECHNOLOGY</u>

- Lap splices
  - Disbonds
  - Corrosion

- Detection sensitivity, and resolution
  - 1/2" x 1/2" disbond
  - 10% metal thinning in top layer over 1/4" x 1/4"

- Scan capability
  - Scan over protruding rivets
  - Maintain consistent U/S coupling
  - Reproducibility of images
  - Scan rate of 1/2 foot of 4-inch lap splice per hour over button-head rivets

FAAREV ISU 4-94

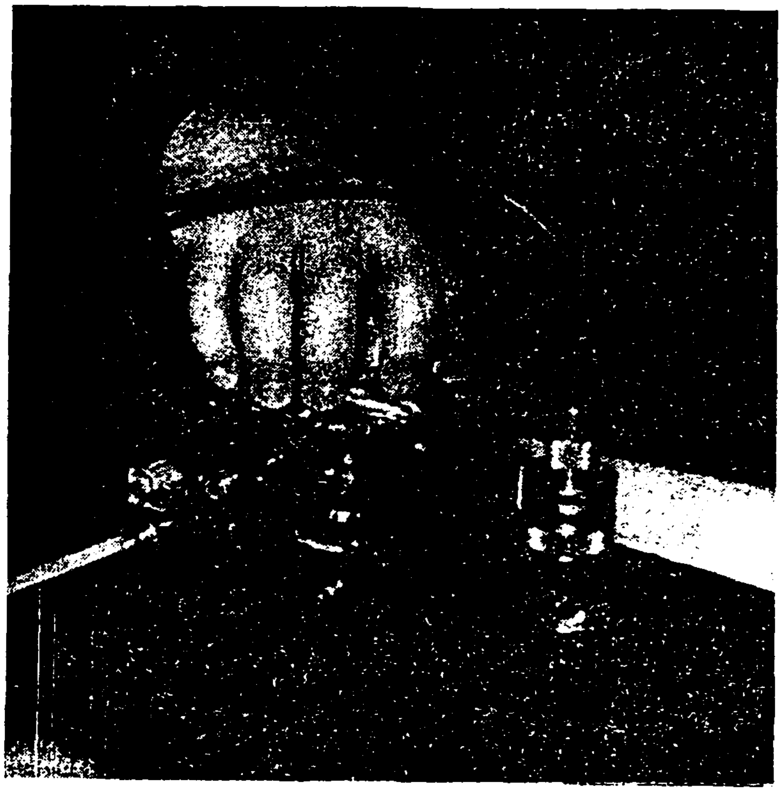
Dripless Bubbler Approach II

FAA Center for Aviation Systems Reliability

PLAN

- Engineer bubbler head to reduce size, weight
- Optimize water delivery and recovery system
- Develop quick connect/disconnect system for rapid transucer interchange
- Improve wear resistance and water containment capabilities of bubbler head
- Fusion of dripless bubbler with existing scanner technology
  - strong interest from McDonnell-Douglas

Dripless Bubbler Combined with MAUS III



MAUS III sweeps out a band at a time, can follow gradual contour, scans long sections of lap splice continuously, and has multi-mode capability.

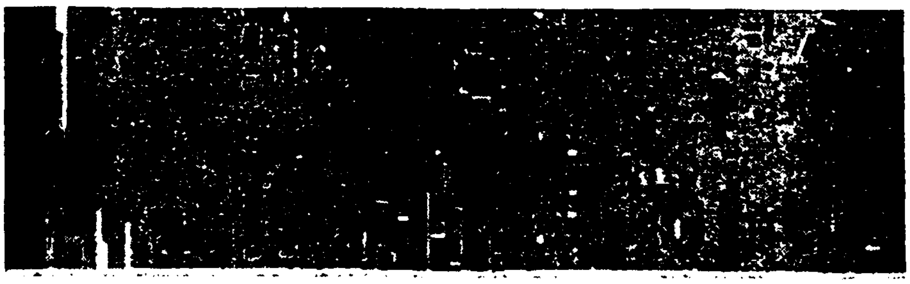


Image of corrosion in Boeing #6 sample as obtained by dripless bubbler and MAUS III with 15 MHz, 2" focus transducer. Scan area = 6.5" x 2"

DB+ MAUS III.pg

General Evaluation Comments

- Portability
  - Compact package is easy to transport and assemble
  - All inspection modes in one package is a unique feature
- Setup Ease
  - Initial setup is very fast and straightforward
  - Simple operator menus are easily understood
- Versatility
  - Various inspection methods allow evaluation of many structures
  - Scanner designs enable inspections in any orientation
  - Data Measurement capabilities are quite useful
- Flexibility
  - Configuration changes accomplished in less then five minutes
  - Easy configuration makes system adaptable for many inspections

MCDONNELL DOUGLAS AEROSPACE

Dripless Bubbler Schedule

FAA Center for Aviation Systems Reliability

1. Reduce size, weight; develop coupling
   - engineer probe head to available transducers
2. Optimize water coupling, foam rings
   - max rivet height, diameter
   - floor ops. or maint. stand, physical dims. of A/C structure
   - Vacuum capabilities, pump capabilities
3. Fusion with scanner
4. On-site testing at AANC

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X-ray Film Densitometer Overview

FAA Center for Aviation Systems Reliability

NEED

- Improve sensitivity in radiographs
- Eliminate the need for multiple film loading
- Recover information from high density regions
- Low-cost instrument

RESPONSE

- Low-cost film densitometer, off-the-shelf components
- Innovative CASR-developed software to acquire images
- Expanded dynamic range using image segmentation
    - increased sensitivity
    - broadened density range

FAAREV ISU 4-94

GOALS FOR TECHNOLOGY

- Improve flaw detection sensitivity
- Reduce film costs
    - elimination of multiple loading
- Contrast sensitivity to 0.5 to 1% contrast sensitivity levels
    - *factor of 2 to 4 improvement*

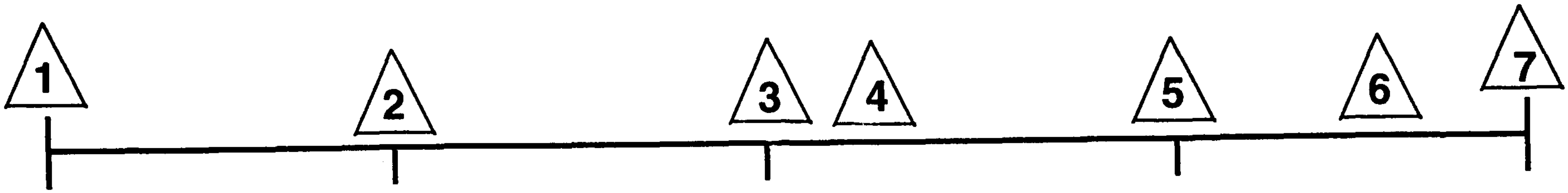
X-ray Film Densitometer Overview

PLAN

- Adapt light box to computer control
- Extend XRVISION graphical user interface for film density data acquisition
- Integrate 16-bit image screen viewer with 16-bit data acquisition software
- Develop calibration procedure for light box and camera

X-ray Film Densitometer Overview

FAA Center for Aviation Systems Reliability



1. Demo initial capability on lab system using industrially supplied radiographs
2. Complete PC control of light box
3. Extend XRVISION GUI to file data acquisition
4. Incorporate 16-bit frame integration
   16-bit frame viewer
5. Beta test at Northwest Airlines, coordinate with AANC
6. Complete calibration procedures for light box and camera
7. On-site test at AANC

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Simulator Overview

FAA Center for Aviation Systems Reliability

<u>NEED</u>

A cost-effective means for evaluating optimal inspection capabilities and limits for x-ray radiography

- Make tactical trade-offs among cost, sensitivity, and spatial resolution
- Evaluate adequacy of inspections for which no established procedure exists
  - repairs
  - commuters
  - unanticipated failure modes beyond design life
- Douglas has requested license
- Interest from Boeing
- Interest from Northwest and Delta

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Simulator Overview

FAA Center for Aviation Systems Reliability

RESPONSE

A workstation-based, Windows-driven rapid x-ray inspection simulator:

XRSIM

- 37 parameters are realistically modeled including:
  - x-ray generator characteristics
  - beam size
  - beam filtration
  - complex shapes from CAD drawings
  - response from various film types
  - set-up configurations

FAAREV ISU 4-94

GOALS FOR TECHNOLOGY

- Collect user feedback on:
  - useability
  - performance
  - convenience
  - features
- Provide user training and ongoing customer support (1-800-HOTLINE)

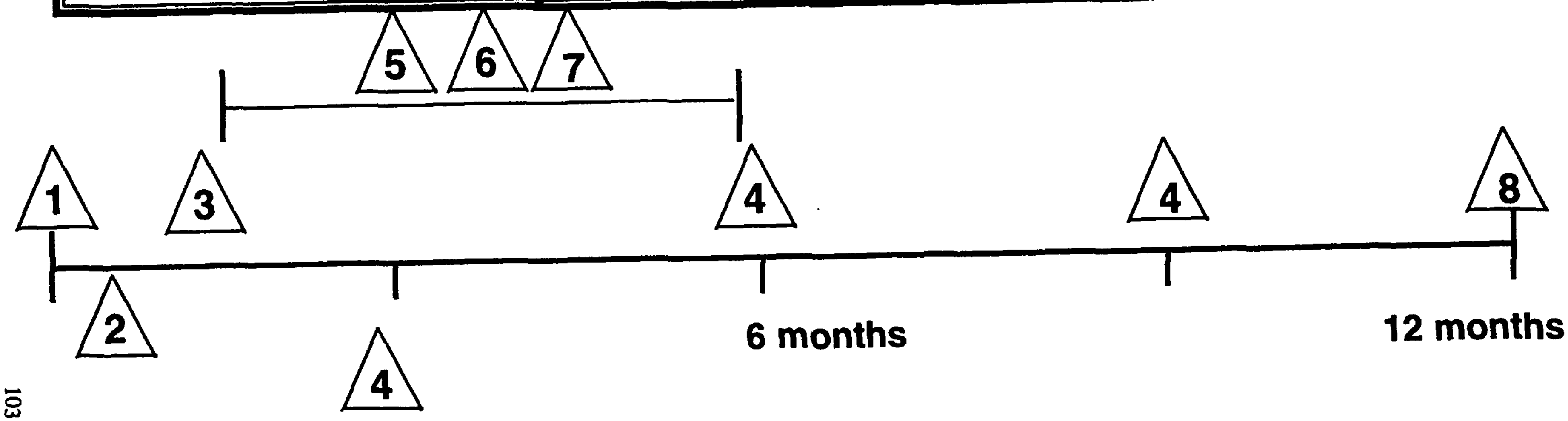
FAA Center for Aviation Systems Reliability

PLAN

- Port XRSIM to low-cost UNIX workstation
- Beta test workstations at several sites (3-4 months each)
- Expand x-ray generator and film data base
- Extend CAD model data base to include additional geometries (by customer request)

Simulator Schedule

FAA Center for Aviation Systems Reliability



1. X-ray sim demo at AANC
2. Develop evaluation form
3. Port XRSIM to lost-cost workstation
4. Beta site test at AANC, OEM, and airlines
5. Addition to x-ray generator data base
6. Addition of film type to XRSIM
7. Addition of CAD object models
8. Summarize and report on evaluations

FAAREV ISU 4-94

EC Probe Calibrator Overview

FAA Center for Aviation Systems Reliability

NEED

Experience and extensive testing of probes from a variety of sources shows need for objective, quantitative method for characterizing eddy current probe quality and standardizing probes used for aircraft inspection. Individual probes can vary by as much as 300-400% in response to flaws, affecting quality and uniformity of testing.

RESPONSE

New probe characterization method based on laser-based mapping of eddy current probe's electromagnetic field

- Quantitative and objective
- Predicts probe response to flaws
- Improve probe design and manufacturing
- Specification and incoming inspection of new probes

FAAREV IBU 4-94

GOALS FOR TECHNOLOGY

- Reduce overall cost for producing instrument to < 10 k$
- Improve sensitivity to low frequency probes (500 Hz and up)
- Re-engineer operating software to improve ease of use
- Function with absolute, differential, and reflection probes
- Spatial resolution of 0.2 mm (8 mils)

EC Probe Calibrator Approach II

FAA Center for Aviation Systems Reliability

PLAN

- Engineer new prototype to reduce system cost to <10 k$
- Improve operation for low frequency probes
  - Thicker witness plate
- Improve user interface with new software, user manuals
  - MS Windows based
- Manufacture additional prototype instruments
- Prepare training program for beta testers
- Arrange for beta-site testing with probe manufacturer, OEM, and airline
  - Preliminary contacts with NDT Engr. and Zetec show strong interest
  - Boeing agreed to participate in validation study

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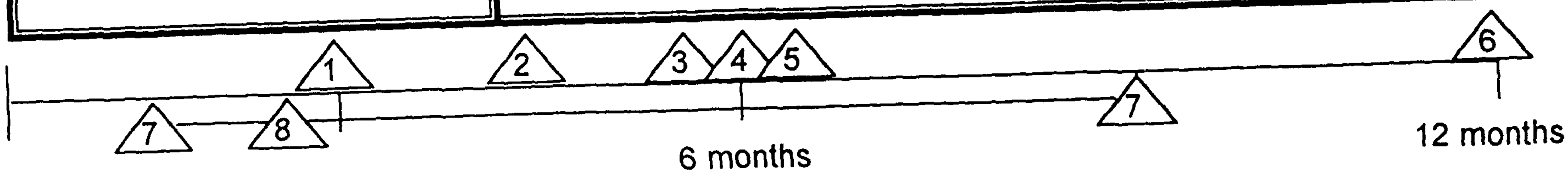
EC Probe Calibrator Schedule

FAA Center for Aviation Systems Reliability



1. Engineer new prototype, reducing cost to <10 k$
2. Improve operation for low frequency probes
3. Improve user interface with new operating software, user manual
4. Complete manufacturing of additional instruments
5. Training for beta-site testers
6. Complete beta testing
7. Correlation of EC Calibrator results with POD study at AANC
8. Comparison with Boeing probe tester

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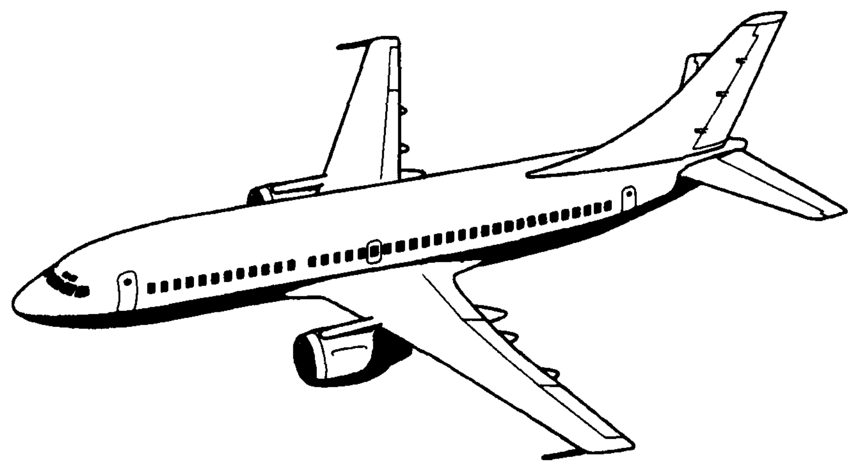
Sandia National Laboratories

Date: 4/8/94

AGING AIRCRAFT NDI VALIDATION CENTER (AANC)



Sandia National Laboratories, NM

Department 2757, Aging Aircraft Project

Development Testing

FAA/AANC NDI Validation Center

Major Objective: to provide the FAA with a tool to perform independent and quantitative performance and cost assessments of inspection techniques.

- Encourage NDI technique development and validation
- Provide test beds to be used by parties in government, private, and international sectors
- Solicit participation of the operators and manufacturers to assure techniques which meet the needs of the air-craft industry

PROGRAM OVERVIEW

Congressionally Mandated - 1988 Aviation Safety Act

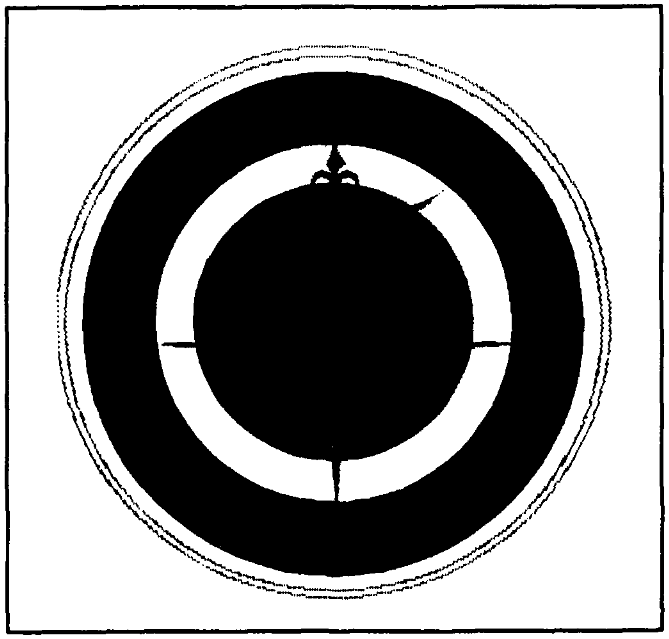
Sandia National Labs Funded - August 1991

Contractual Participants - Science Applications Int'l Corporation
New Mexico State University
AEA Technology (Harwell)

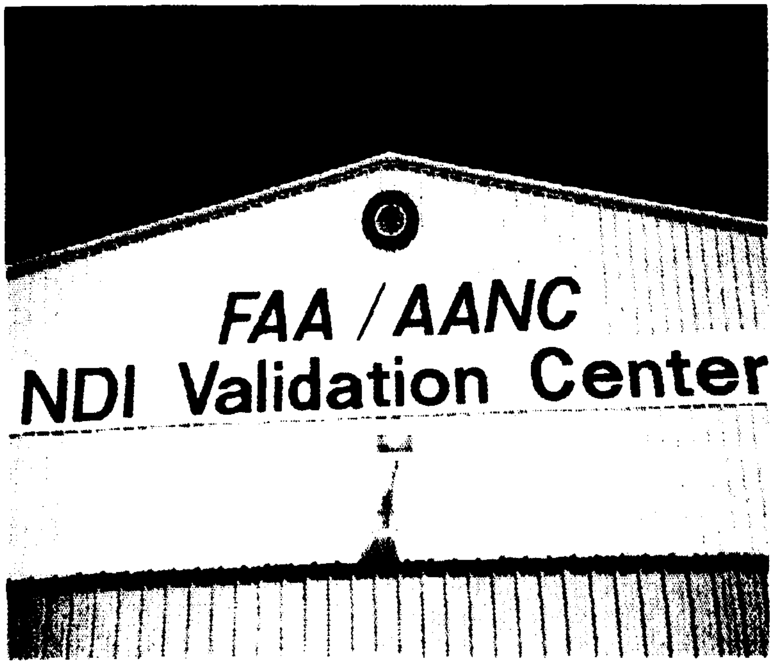
Customer:
- **Federal Aviation Administration (FAA) Tech Center**
- **FAA Regional Offices**
- **OEMs, Operators, 3rd Party Maintenance Facilities**

Managed: **Chris Seher (FAA/Aging Aircraft)**
Dick Johnson (FAA/AANC)
Pat Walter (Sandia Labs)

☛ COMPLETED ACTIVITIES



◆ Hangar Acquired/Renovation Completed *Jan. 1993*

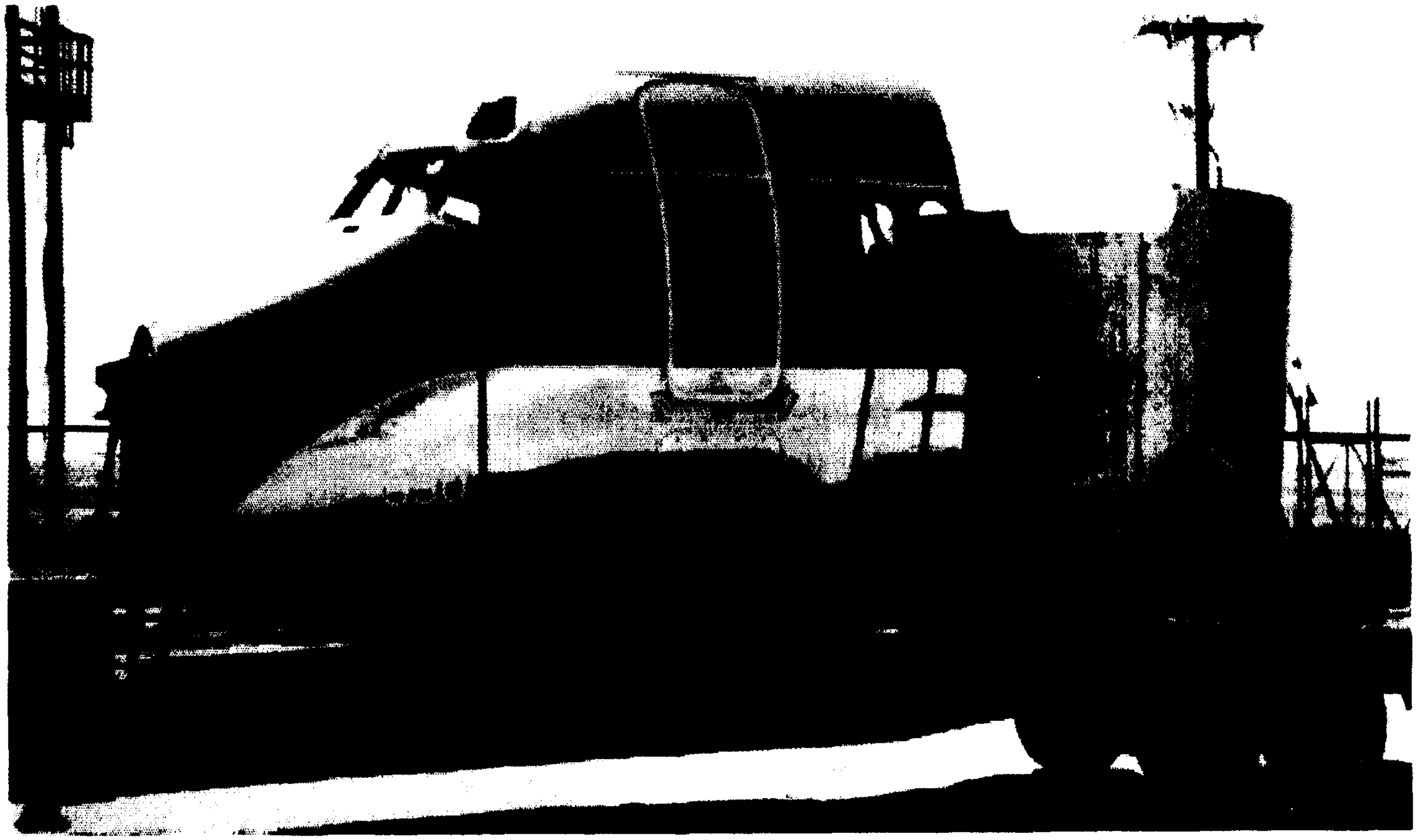


Located west end Albuquerque International Airport

◆ B737 Testbed Aircraft Acquired/ Configured - *Nov. 1992*

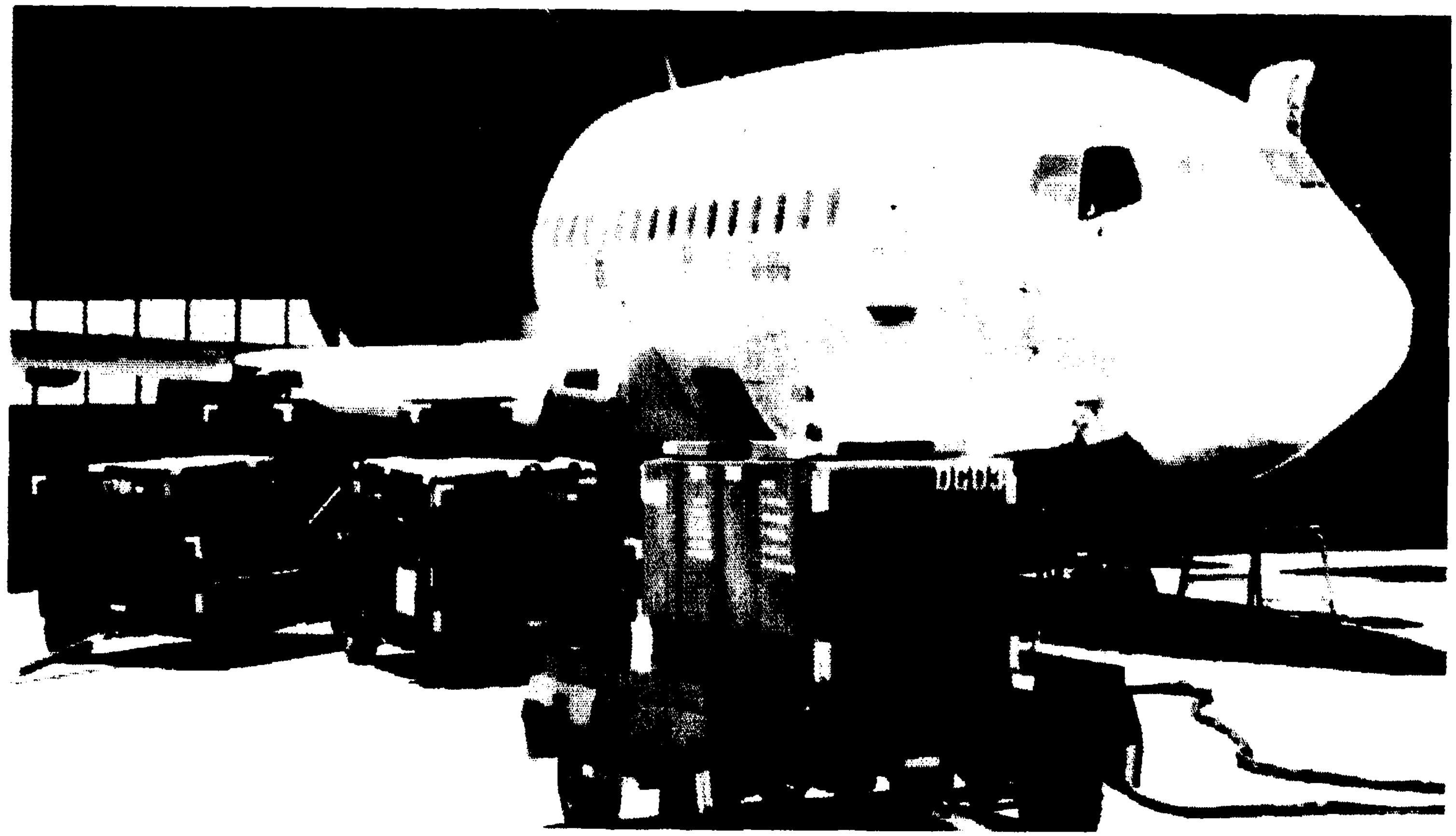
B737-200/46,358 Cycles/38,342 Hours/Line #49 (1968)

- DC9 Fuselage Structure Acquired *June 1993*



DC9/64,360 Cycles/56,520 Hours (1973)

- **Aircraft Pressurization Capability Established - *July 1993***



Airstart/APU Loaned to Sandia by USAF/Kirtland AFB

Sandia National Laboratories

◆ Aircraft Turbine Engine Reliability and Inspection Investigations
Sept. 1993

DOT/FAA/CT-92/29

FAA Technical Center
Atlantic City International Airport
N.J. 08405

Aircraft Turbine Engine Reliability and Inspection Investigations

September 1993

Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

U.S. Department of Transportation
Federal Aviation Administration

Development Testing

Department 2757, Aging Aircraft Project

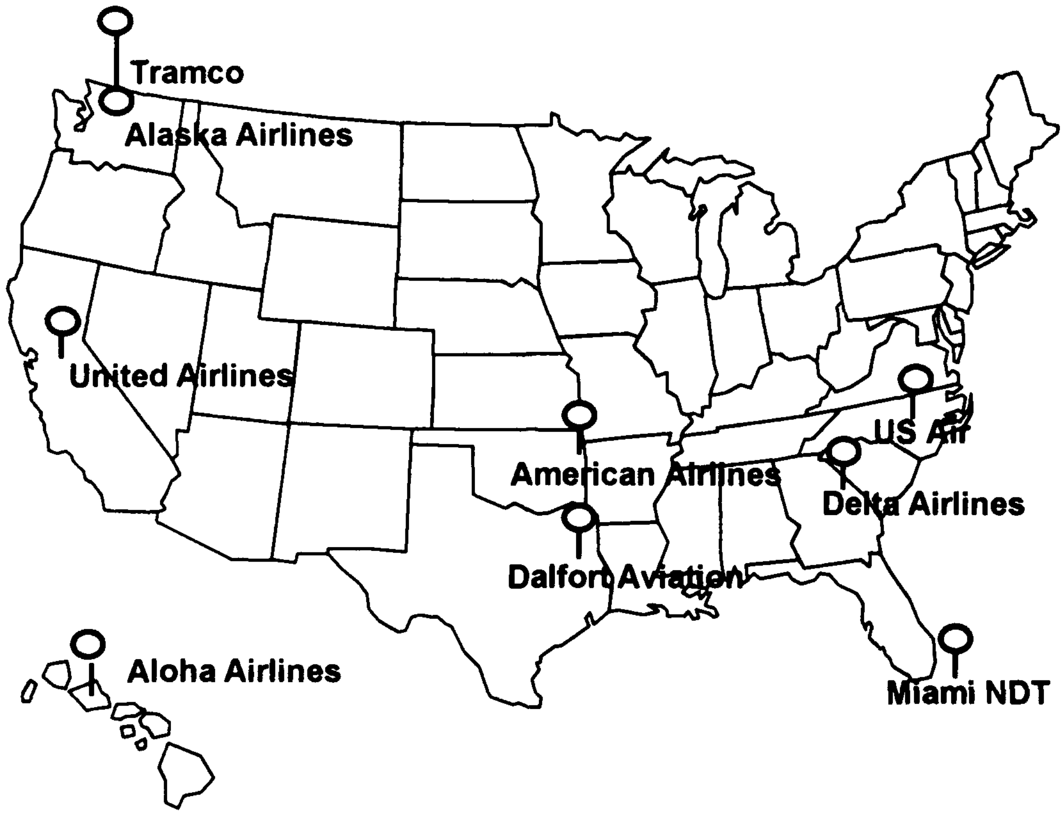
- **Thirty-One (31) NDI Activities Completed/ Documented in FAA/AANC Validation Center *CY1993***

- **Emerging Technologies Document Final/Distributed - *March 1994***

Emerging Nondestructive Inspection Methods for Aging Aircraft

Sandia National Laboratories

◆ Eddy Current Inspection Reliability Experiment Completed - *March 1994*



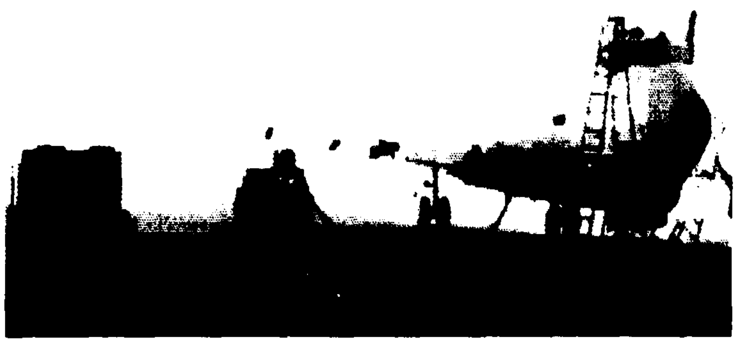
Department 2757, Aging Aircraft Project

Development Testing

Date: 4/8/94

Sandia National Laboratories

◆ Experimental Localized Strain Assessment of B737 for FAA
March 1994



Department 2757, Aging Aircraft Project

Development Testing

Background and Goals

1. Investigate strain fields in fatigue critical 737 joints
   - instrument key lap splice joint bays inside and out
   - instrument like bays fore and aft of wing to assess variations

2. Compare with simulated 737 fuselage testing by Foster-Miller which experienced multi-site failure at 75,000 pressure cycles
   - determine effects of boundary conditions
   - match strain gage locations

3. Validation of stress and fatigue analyses
   - finite element models at VNTSC and Georgia Tech

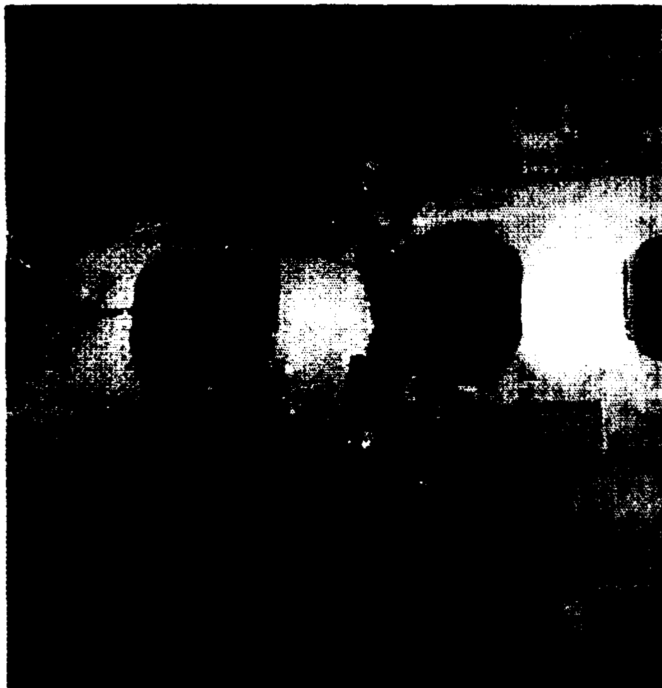
4. Support NASA analytical and experimental programs in multi-site fatigue cracking
   - more detailed experimental data than limited NASA tests

5. 100 strain channels recorded in five lap splice bays with 100 percent data return

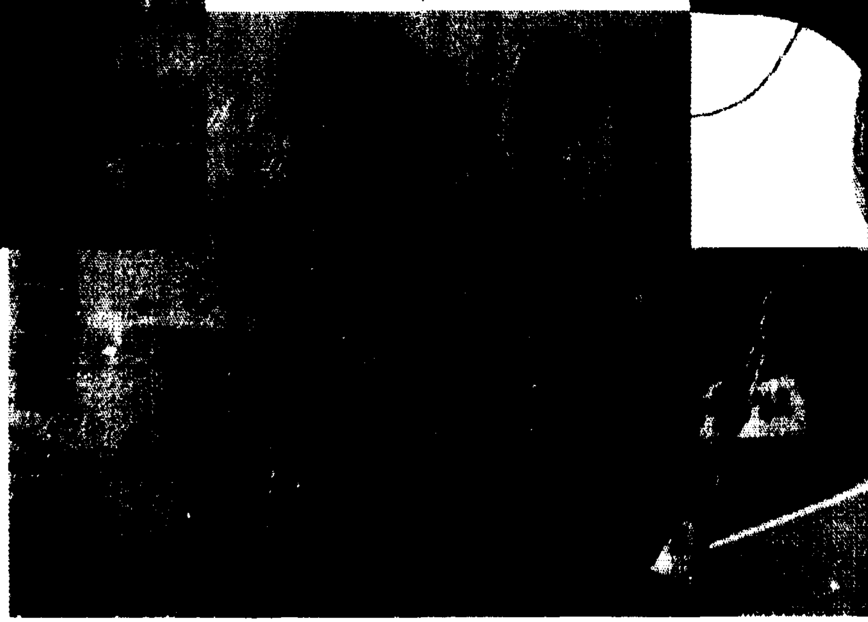
Date: 4/13/94

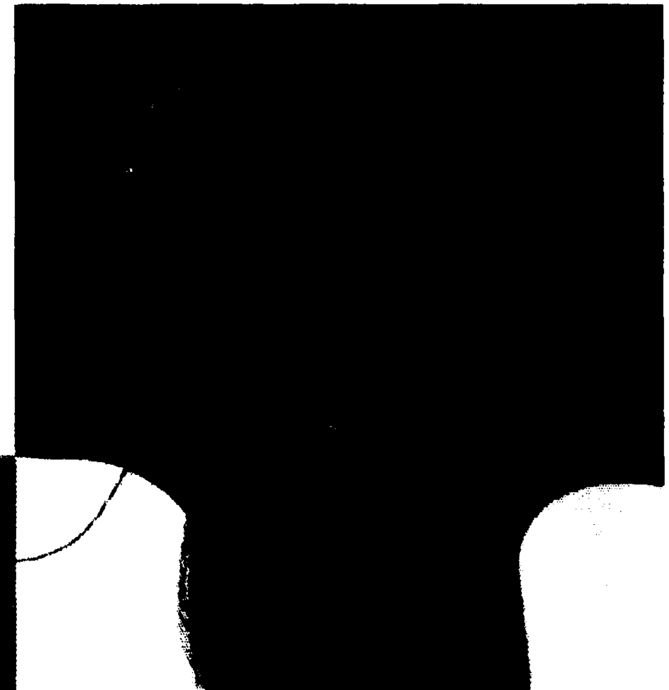
Sandia National Laboratories

Strain Gage Installations Inside and Outside the Fuselage



Close-up of strain gages across the lap splice joint (Stringer 14)





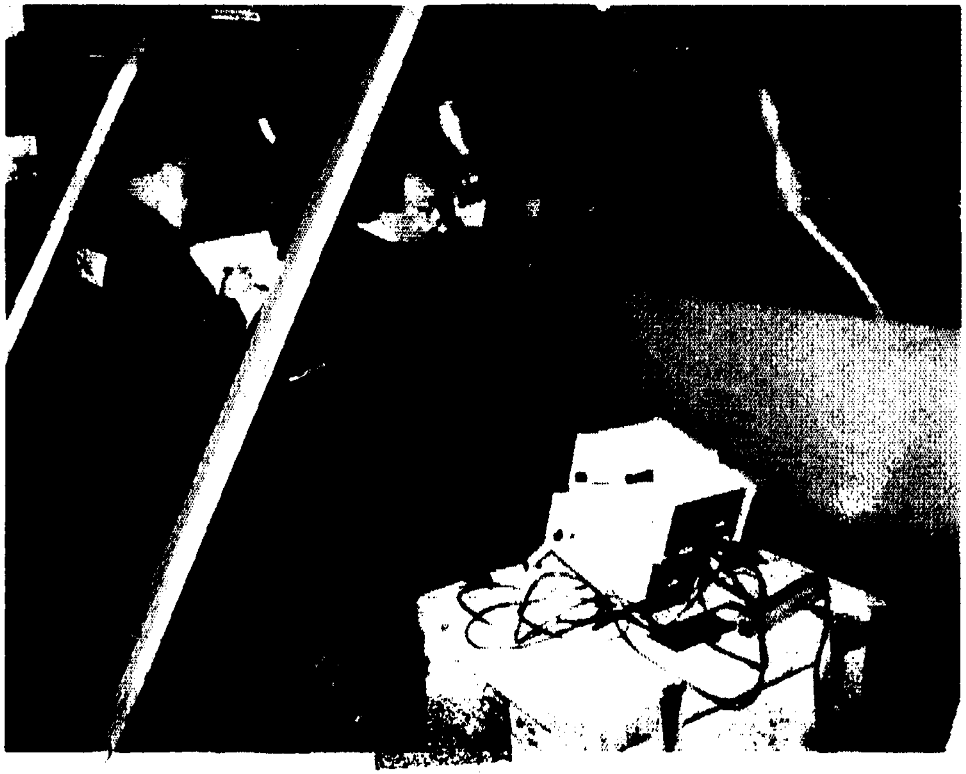
External Strain Gages around stringers 10 & 14 (Body Station 475)

Internal Strain Gages - lap splice inner skin and substructure

Development Testing

Department 2757, Aging Aircraft Project

- **Magneto Optic Eddy Current Imager Validation Program Completed**
  April 1994



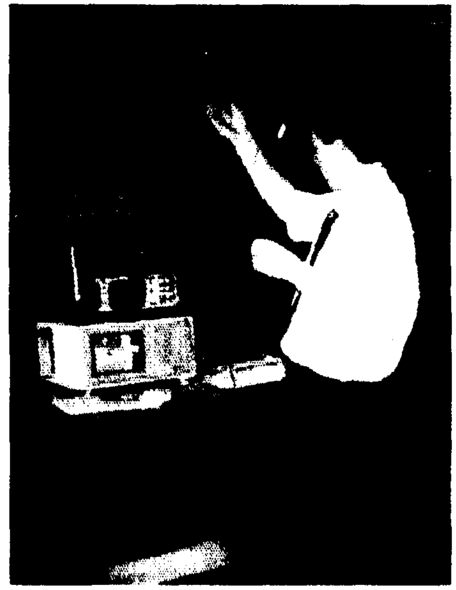
Cost Benefit Analysis Performed by NUTC

Sandia National Laboratories

◆ Manual/Semi-Automated/Automated Scanner Assessment Completed *April 1994*

McDonnell Douglas

DuPont/CalData/Zetec



Krautkramer Branson Hocking

Other Participants: Failure Analysis, SAIC Ultra Image, Sierra Matrix, Smart EDDY, Panametrics, Krautkramer Branson Hocking, MATEC Sonix, Infometrics, ABB Amdata

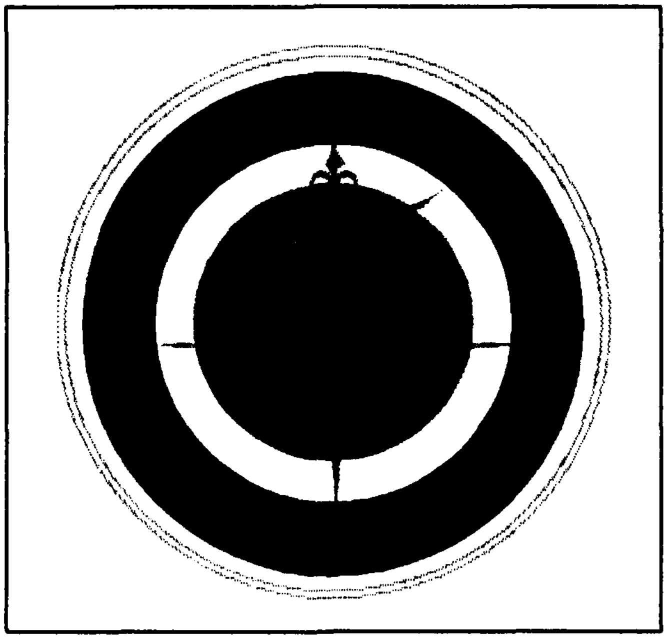
- **Enhanced Visual Aids Assessment Completed - *April 1994***

Inspections With Olympus Videoscope

Rear Pressure Bulkhead

Lap Joint

FUTURE ACTIVITIES



Date: 4/13/94

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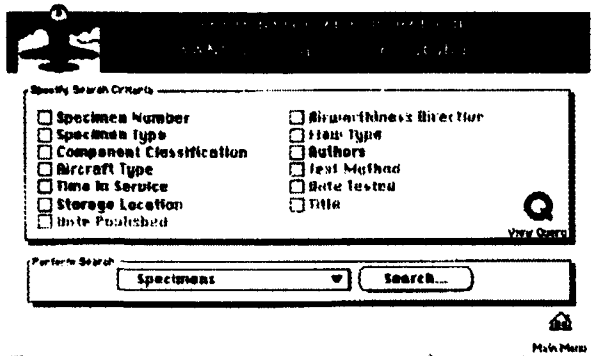
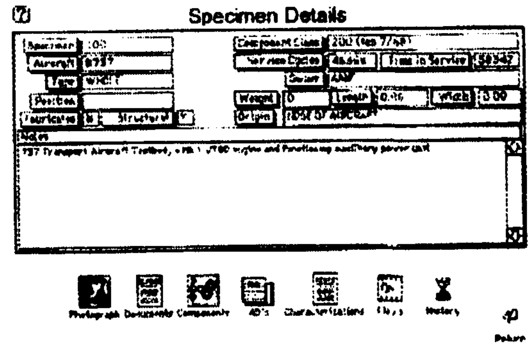
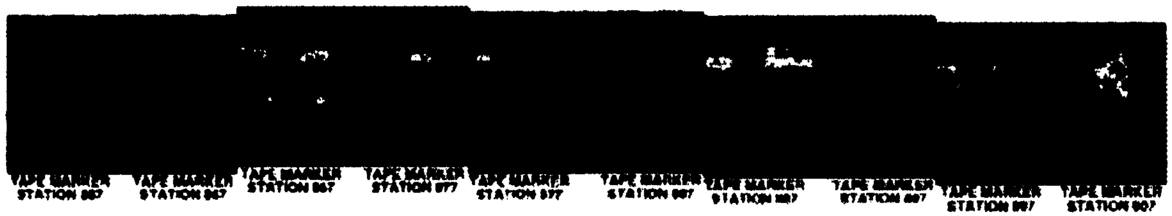
◆ Database Development for NDI Assessment





Stores Specimen Information and Reports



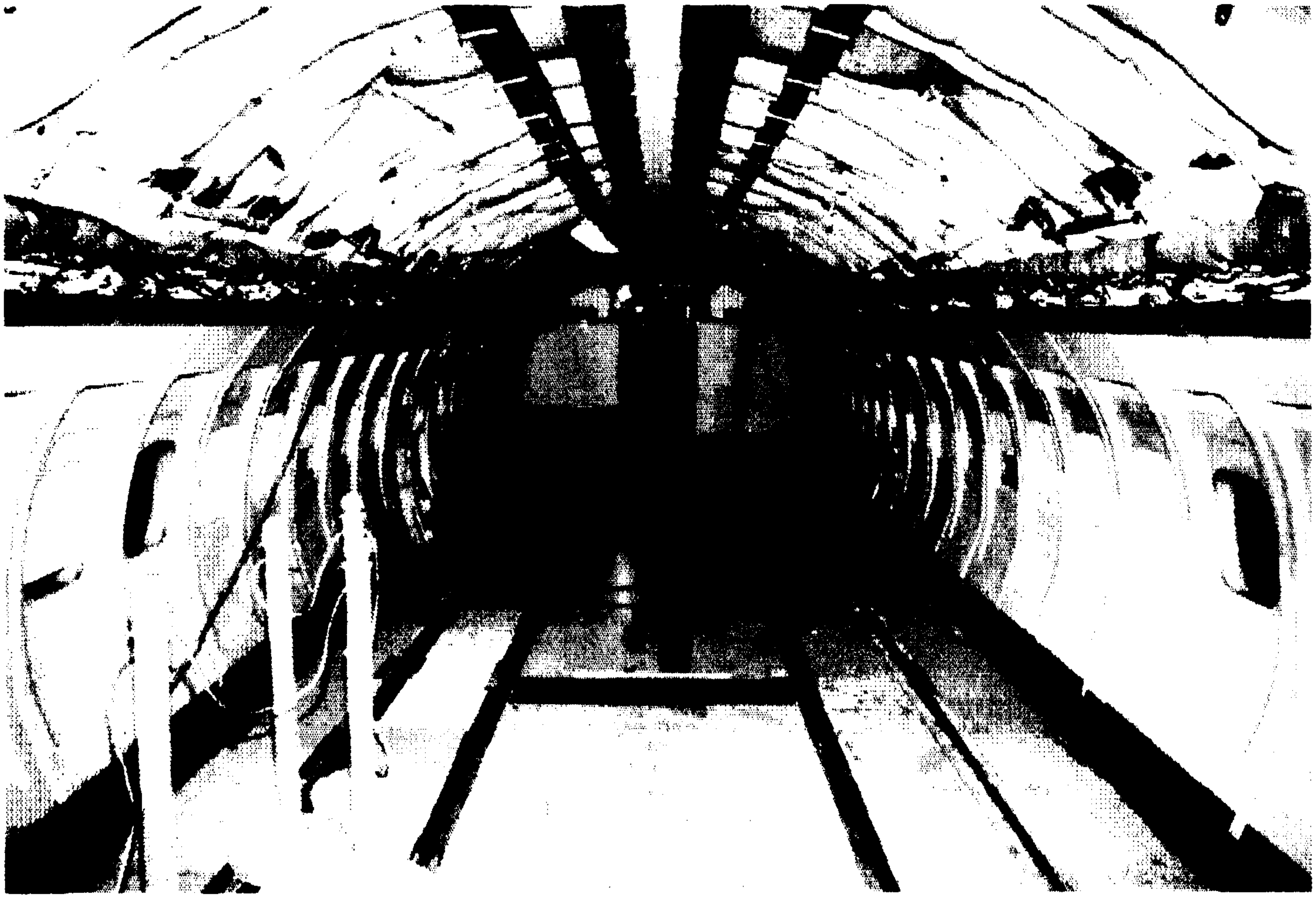
Thermal Wave Images of 737 Testbed Fuselage Section

Stores All Inspection Results

Development Testing

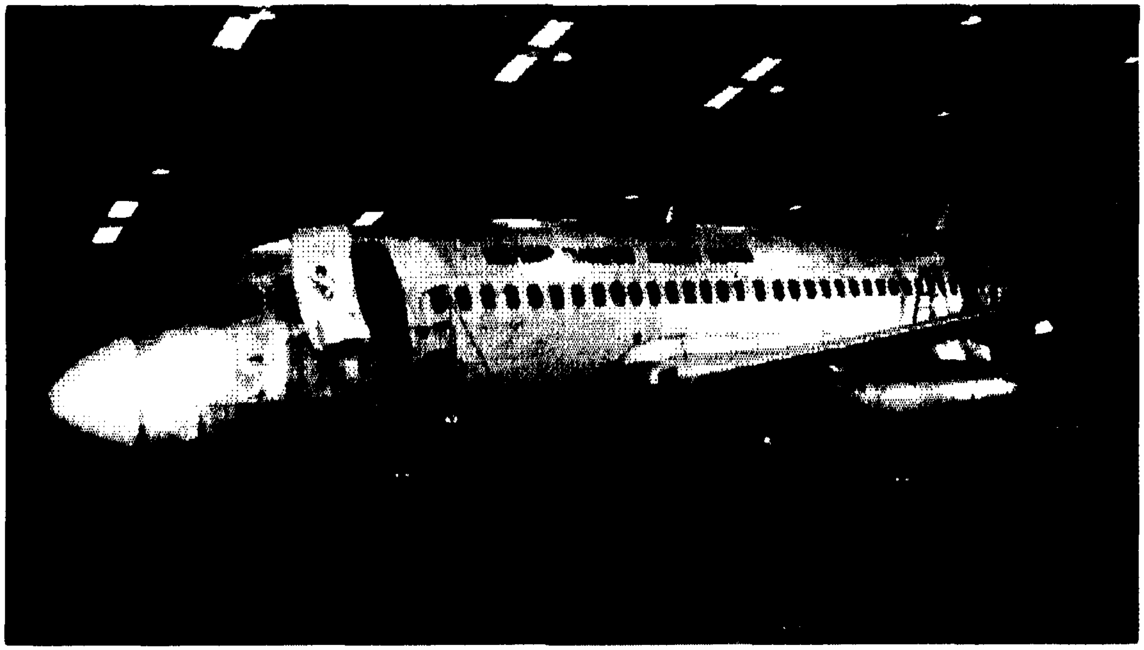
Department 2757, Aging Aircraft Project

◆ Baseline Assessment of B737 Aircraft



Resource Development - Baselining the 737

Goal: **To determine and document the flaw profile of the AANC 737 testbed aircraft. Specifically, we will use current visual and NDI technology and techniques similar to that used in C, D level checks, and examine and record the detailed flaw profile (crack, corrosion and disbond condition) of the entire 737 fuselage (interior and exterior) and wing exterior.**



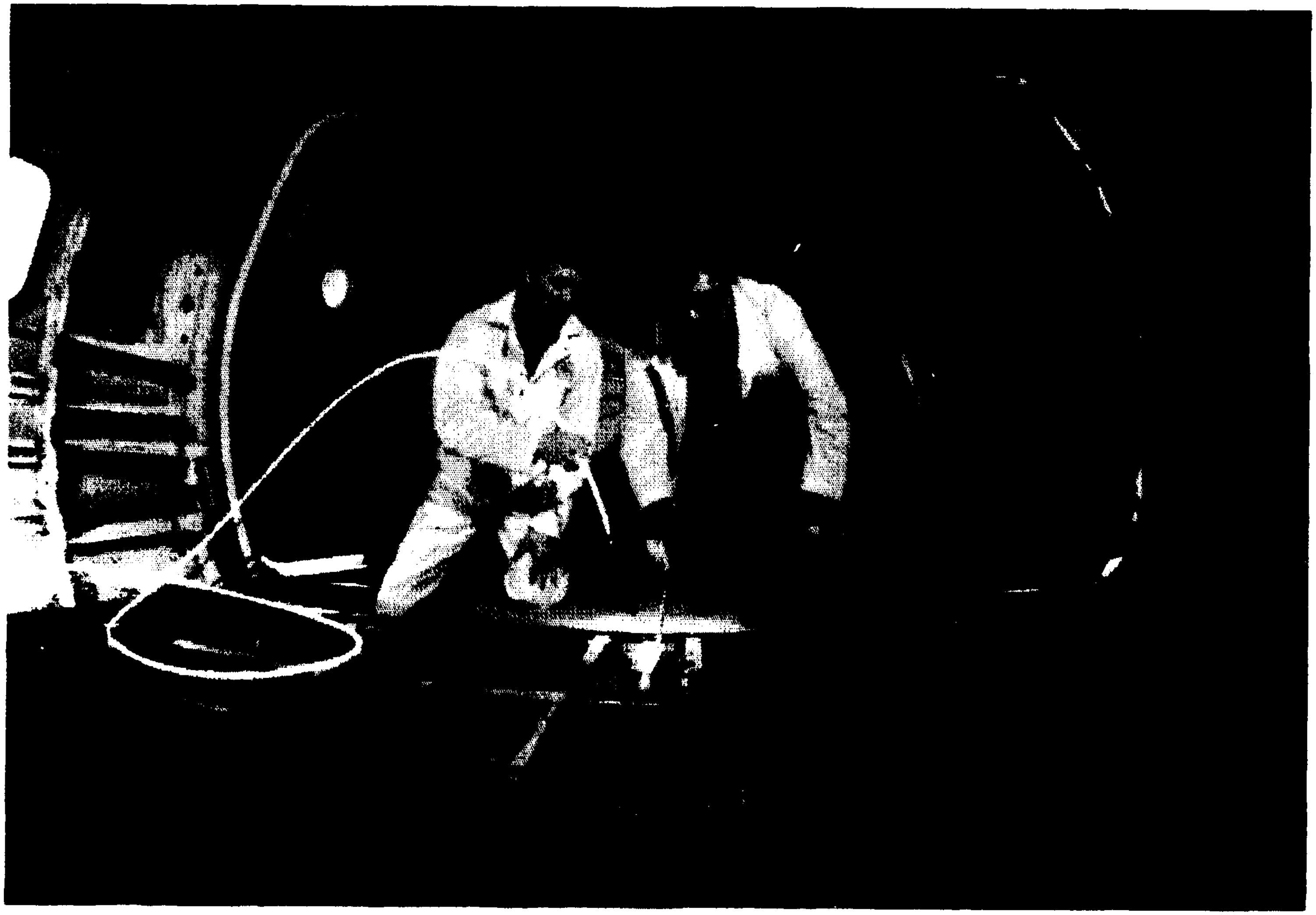
Resource Development - Baselining the 737

Baselining Program Plan:

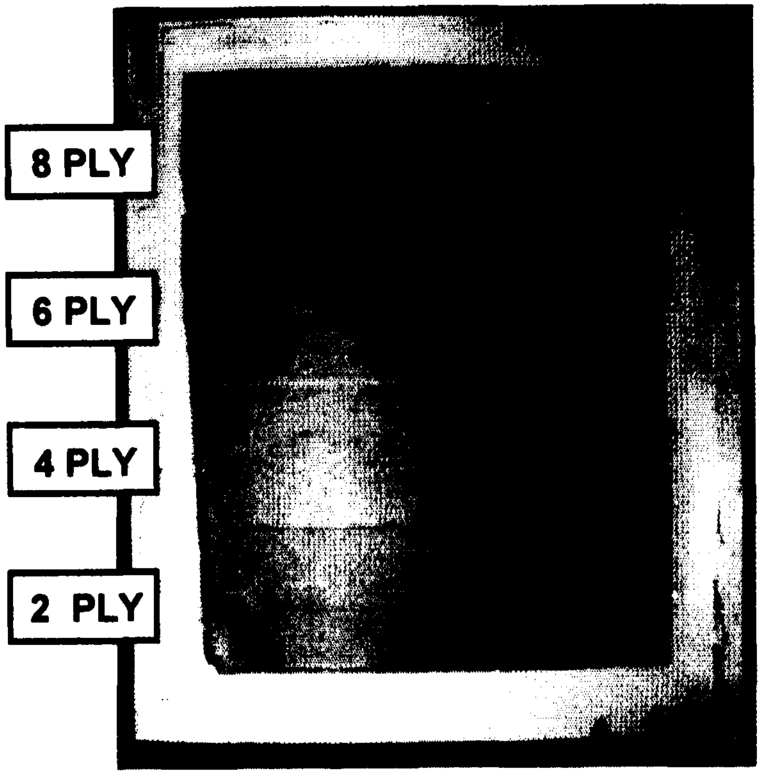
- Perform "modified" C, D-Check level structural inspection
- Focus on fuselage and other maintenance critical areas
- Focus on areas directed by AD's, SB's, CPCP and SSID's
- Have Tech/Ops International participate in planning, execution, and documentation
- Use FAA qualified visual and NDI inspectors with 737 experience
- Have USAF NDI technicians from Kirtland AFB available on a non-interference basis to supplement contracted inspectors

Have 4 Program Phases: Planning, Organizing, Inspecting and Documenting

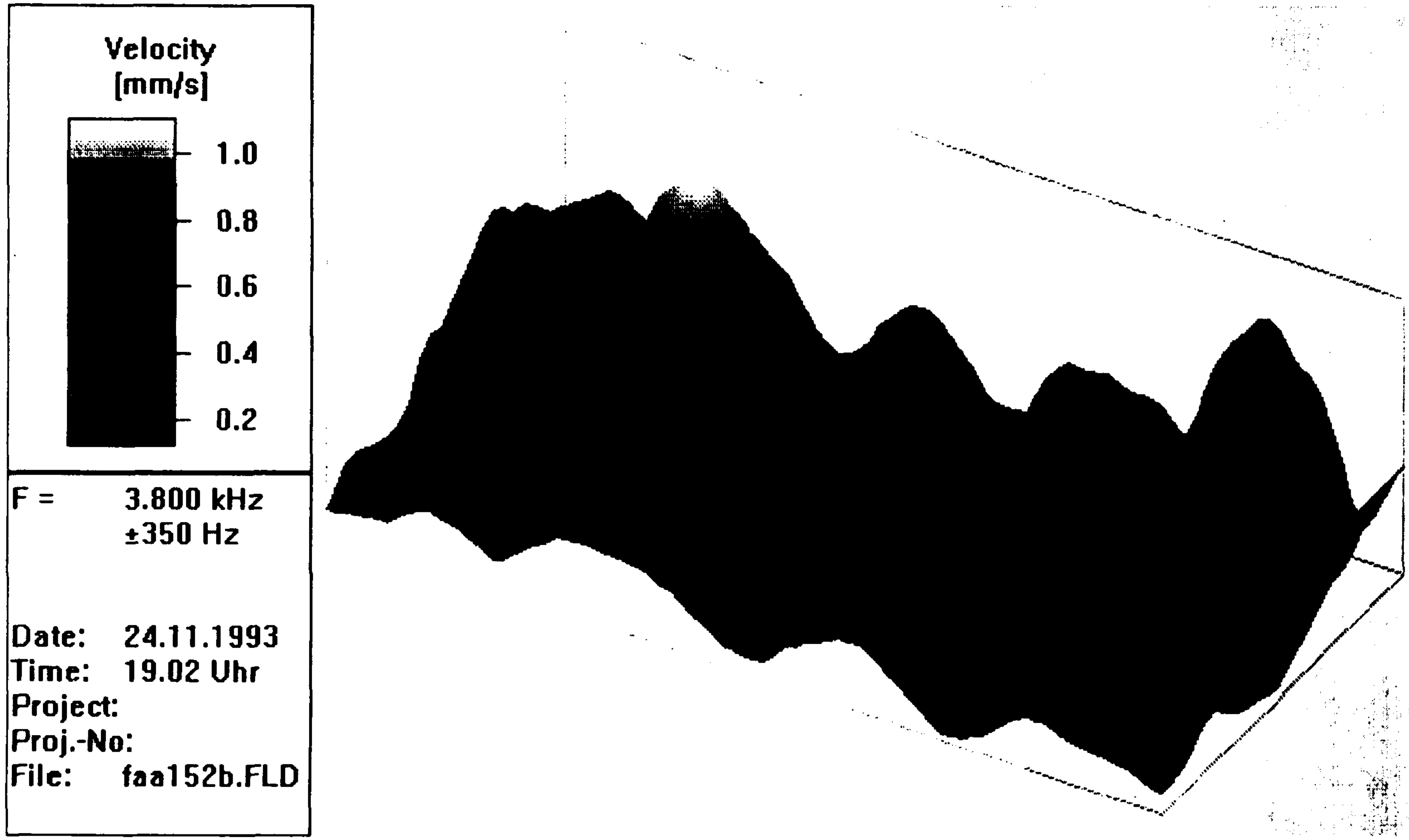
◆ Visual Experimentation Program



◆ Structural Airframe Enhancement With Composites



Participation with FAATC/Delta/Lockheed



FAA Textron repair patch sample.
Laser Doppler with remote Acoustic Excitation.

Sandia National Laboratories

◆ Harmonization of Airframe Inspection Procedures

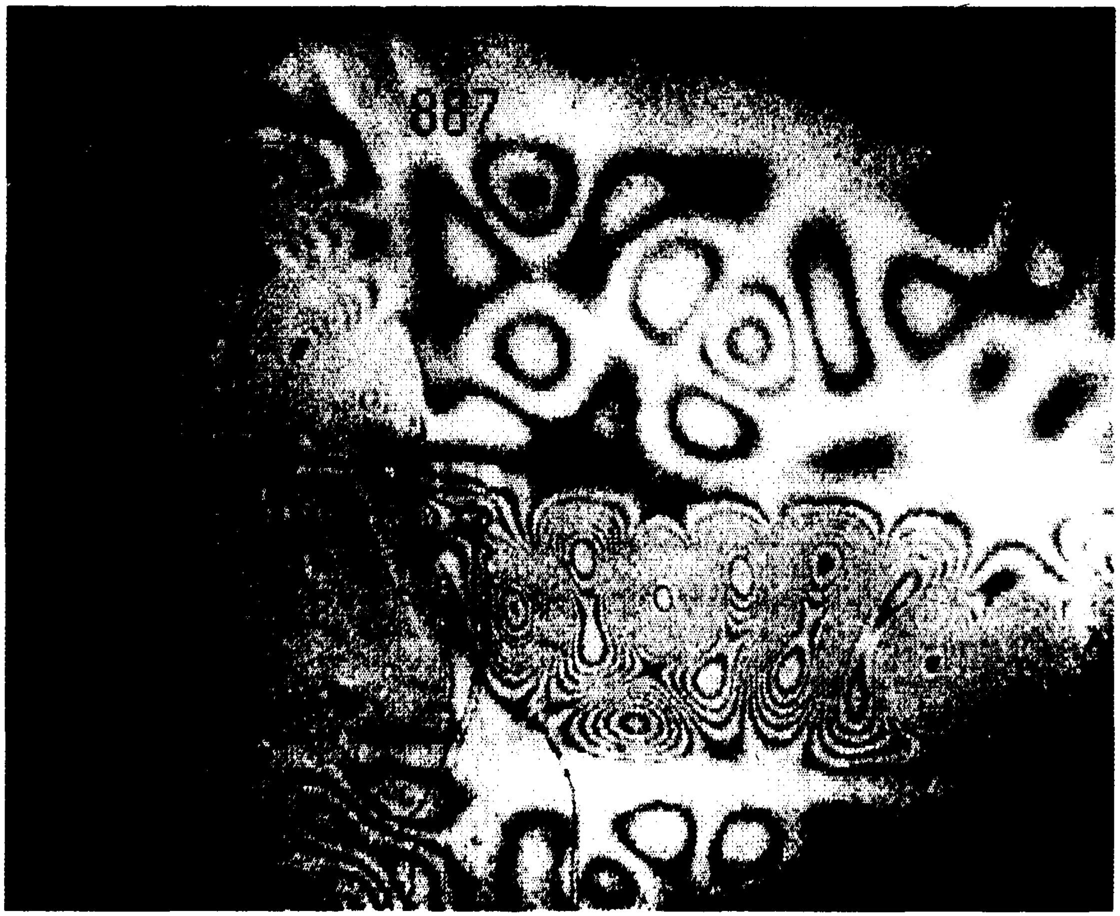
Development Testing

Department 2757, Aging Aircraft Project

Date: 4/13/94

Sandia National Laboratories

◆ Coherent Optics Computational Strain Capability



Department 2757, Aging Aircraft Project

Development Testing

Date. 4/8/94

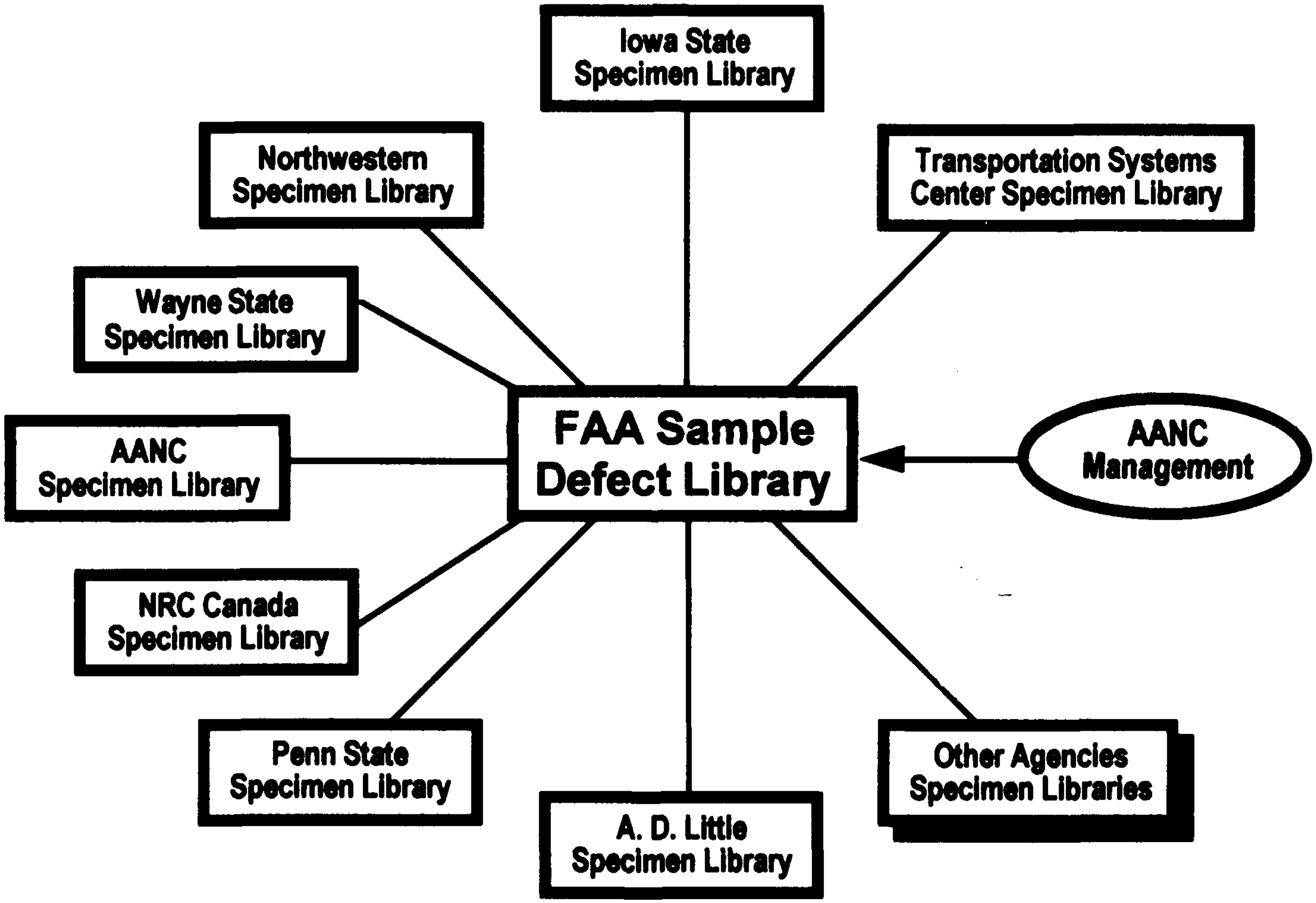
Sandia National Laboratories

◆ ATA NDT Forum Host - *Nov. 1994*

Development Testing

Department 2757, Aging Aircraft Project

SDL is Comprised of Numerous Individual Libraries



FAA Sample Defect Library Tracks the Specimens Contained in Contractor's Individual Libraries

Goals of Sample Defect Library

The FAA Sample Defect Library was established to:

- **Improve NDI development programs through the sharing of specimens and information**
- **Foster teamwork among FAA/Aviation Industry researchers**
- **Eliminate the costly production or acquisition of redundant test**

The FAA Sample Defect Library is <u>not</u> an attempt to:

- **Interfere with ongoing projects**
- **Move all samples to a single location**
- **Use up anyone's authority or control over a project**

Sandia National Laboratories

Date: 4/13/94

Sample Inventory from NRC-Canada Library

Defect Library Inventory — IAR/NRC — 28 February, 1993

No.	SPECIMEN	JOINT TYPE	corr	LOCATION	SIZE (in) Lap/Butt	D SIGHT	X RAY	EDDY CURRENT	OPENED	NOTES: original condition/ actions
	727 N4739									as of 30 Sept 91
	ex Pan Am									flight hours: 56,784
	s/n 19459									flight cycles: 49,256
	line# 530									
1	39L1	LAP		STR# 19, FS 720-720A	17	Y		Y		repaired, excess sealant
2	39L2	LAP		STR# 19, FS 720A-720B	16	Y		Y		
3	39L3	LAP		STR# 26, FS 1090-1100	17	Y		Y		top row mushroom,repaired,new skin,liq shim
4	39L4	LAP		STR# 20, FS 1070-1090	16	Y		Y		new lower skin
5	39L5	LAP		STR# 20, FS 1090-1100	16.75	Y		Y	Y	new lower skin, N Ray, dissassembled,

No.	SPECIMEN	JOINT TYPE	corr	LOCATION	SIZE (in) Lap/Butt	D SIGHT	X RAY	EDDY CURRENT	OPENED	NOTES: original condition/ actions
	727 N4743									as of 30 Sept 91
	ex Pan Am									flight hours: 56,866
	s/n 19463									flight cycles: 49,527
	line# 552									
6	43L1	LAP		STR# 19, FS 460-480	16.75	Y		Y		
7	43L2	LAP		STR# 20, FS 1090-1100	15.5	Y		Y		
8	43L3	LAP		STR# 19, FS 500-520	16	Y		Y		
9	43L4	LAP		STR# 19, FS 520-540	16	Y		Y		
10	43L5(R3)	LAP		STR# 19, FS 720-720A	16	Y	Y	Y		mech repair at one end
11	43L6	LAP	C	STR# 19, FS 480-500	15.5	Y		Y	N	original . corrosion chamber control specimen
	43L7	LAP		STR# 20, FS 1070-1090	14.5					lower skin replaced = c/w sealant,tk upper skin
12	43L7R		C		14.5	Y	Y	Y	Y	REBUILT outer skin exposed in lap
13	43R1	LAP		STR# 19, FS 680-700	17	Y	Y	Y		rough condition, 1 repair at end
14	43R2	LAP		STR# 19, FS 700-720	17.5	Y				

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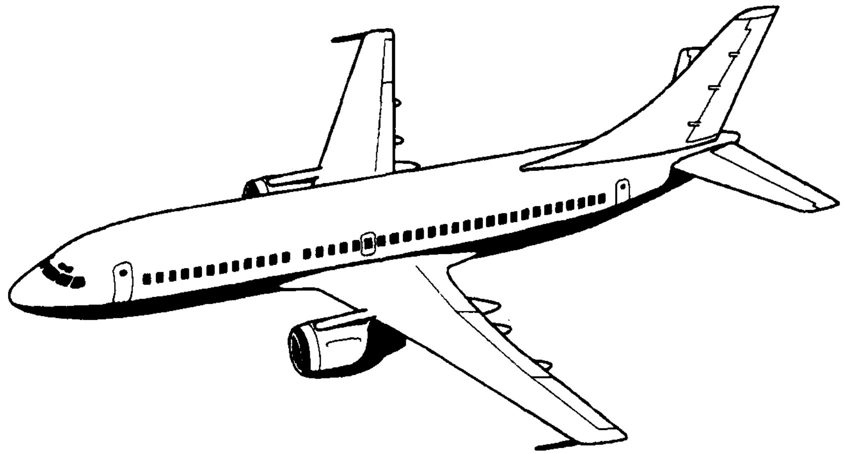
Validation and Tech Transfer



Patrick L. Walter

Sandia National Laboratories, NM

◆ Validation Process Defined/Coordinated with OEMs, FAA, ATA - *July 1992*

- Validation process intent is to provide an independent, quantitative, and systematic assessment of both the reliability and the implementation costs of an NDI process.

The Role of the Aging Aircraft NDI Development and Demonstration Center in the FAA Validation Process

7/14/92

INTRODUCTION

Purpose and Scope

The purpose of this document is to describe a systematic approach to be followed by the Aging Aircraft NDI Development and Demonstration Center (AANC) in providing independent validation capabilities to FAA NDI initiatives. The approach encompasses a logical sequence of individual tasks and levels of involvement associated with the development of NDI systems and procedures.

FAA NDI Validation Process

Development Phase	Validation Activities
1. Conceptual	- Identify: 1. Interrogated component material type 2. Flaw types and inspection 3. Inspector requirements 4. Critical elements - Verify in laboratory - Assess inherent capabilities (theoretical) - Estimate (order of magnitude) capital equipment costs and material and power needs for routine operation.
2. Preliminary design	- Test in laboratory on specified test samples - Identify and enumerate preliminary: 1. NDI equipment 2. Inspector requirements 3. Facility requirements

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FAA NDI Validation Process (Continued)

Development Phase	Validation Activities
3. Final Design	- Experiment to assess factors affecting reliability - Demonstrate feasibility through "blind" procedures - Gather inspection time data - Update procedures and inspector requirements - Early field trials
4. Field Implementation	- Prepare (or specify) validation assemblies - Finalize procedures and inspection requirements - Conduct controlled trials using independent inspectors - Industry Beta-site testing

◆ Technology Development Process Defined/Coordinated with OEMs, FAA, ATA - *Oct. 1992*

- Technology development is the process by which NDI systems or information, in whatever form, are shaped into a product or service usable in airline maintenance programs.

The NDI Technology Development Process as Implemented by the FAA Aging Aircraft NDI Development and Demonstration Center

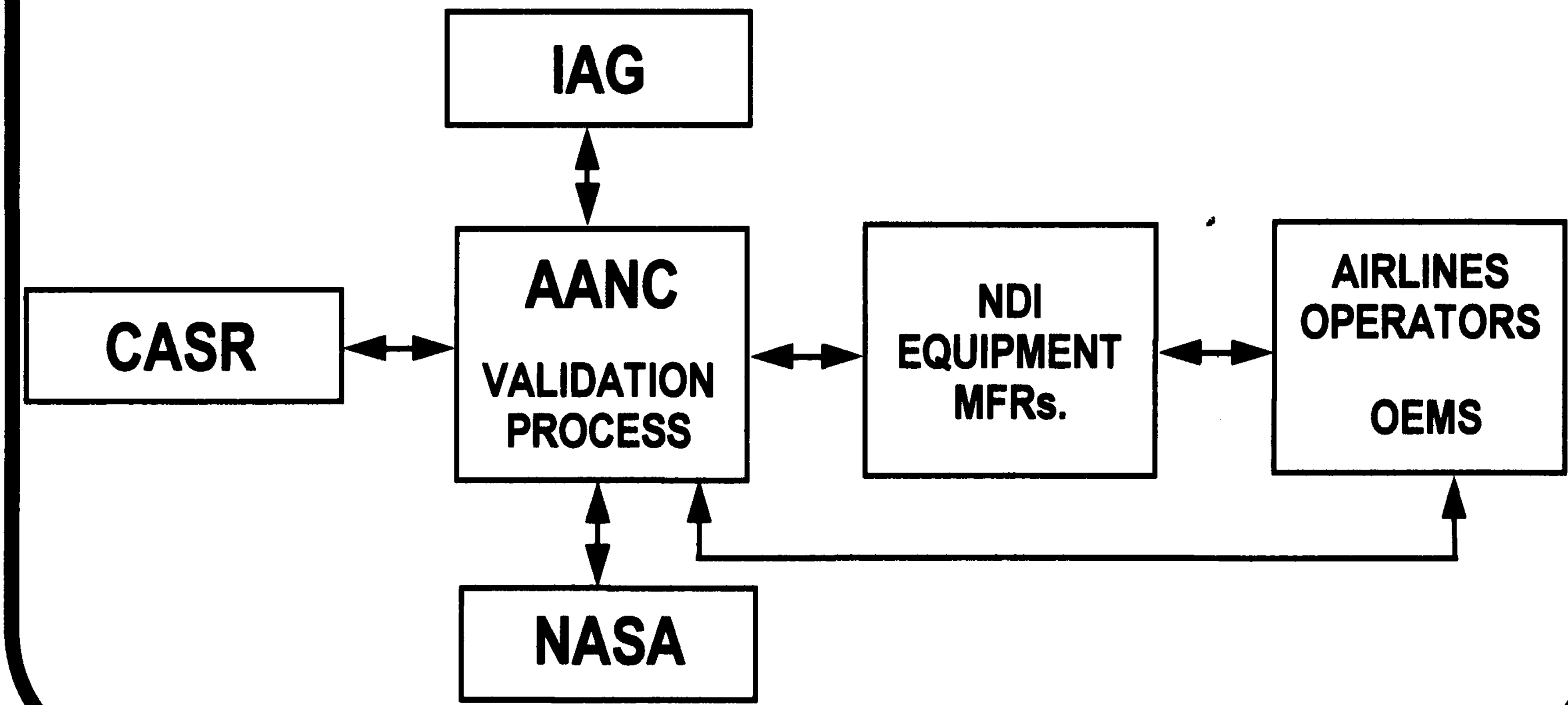
10/27/92

Background

Today, many airlines are operating aircraft beyond their original design lifetimes. To help ensure the continued airworthiness of this aging commercial fleet, the Federal Aviation Administration (FAA) has established the National Aging Aircraft Research Program. A significant portion of this program concerns nondestructive inspection (NDI) technologies and their application to aging aircraft. Development of new NDI technologies must keep pace with the expanding requirements for

FAA NDI Technology Development Process

Control Flow Diagram



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FAA/AANC NDI Validation Center Implementation Plan

Define a technology flow process

Define an approval cycle for this flow process

Define a technology validation process
- reliability assessment
- cost effectiveness

Acquire a facility

Acquire test specimens
- including high cycle aircraft

Define / establish a database

Implement trial process

Present results to FAA/ manufacturers/operators

Process in place to move FAA program technology to hangar floor

Validation Process First Application

Magneto-Optic/Eddy Current Imager (MOI) - A NDI instrument using unconventional eddy current excitation to form images of cracks directly and in real time.

WHY MOI?

- **It's commercially available to enter Phase 3 of the validation process and complete this process through Phase 4. This will provide a deliverable to the operators and OEMs for their critique and encourage buy-in to the process for subsequent validated inspection tools from the FAA's NDI program.**
- **The MOI has been approved by Boeing and Douglas for application on their aircraft. The MOI price is 30K$ and only American and Tower Air are now routinely using this instrument. Favorable findings would encourage rapid expansion of this new technology into other inspection facilities.**
- **The MOI has the potential to make a significant contribution to commuter inspection facilities.**
- **The MOI can be integrated into the existing POD of Eddy Current Lap Splice Experiment funded by the FAA. The existing experiment will provide a direct baseline for assessment of MOI inspection reliability.**

Date: 4/13/94

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Date: 3/31/94

MOI Validation

Floyd W. Spencer
AANC

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Goal

Perform reliability assessment and cost benefit analysis for Magneto Optic/Eddy Current Imager manufactured by PRI Instrumentation.

The assessments involved beta site testing at 3 airline maintenance facilities.

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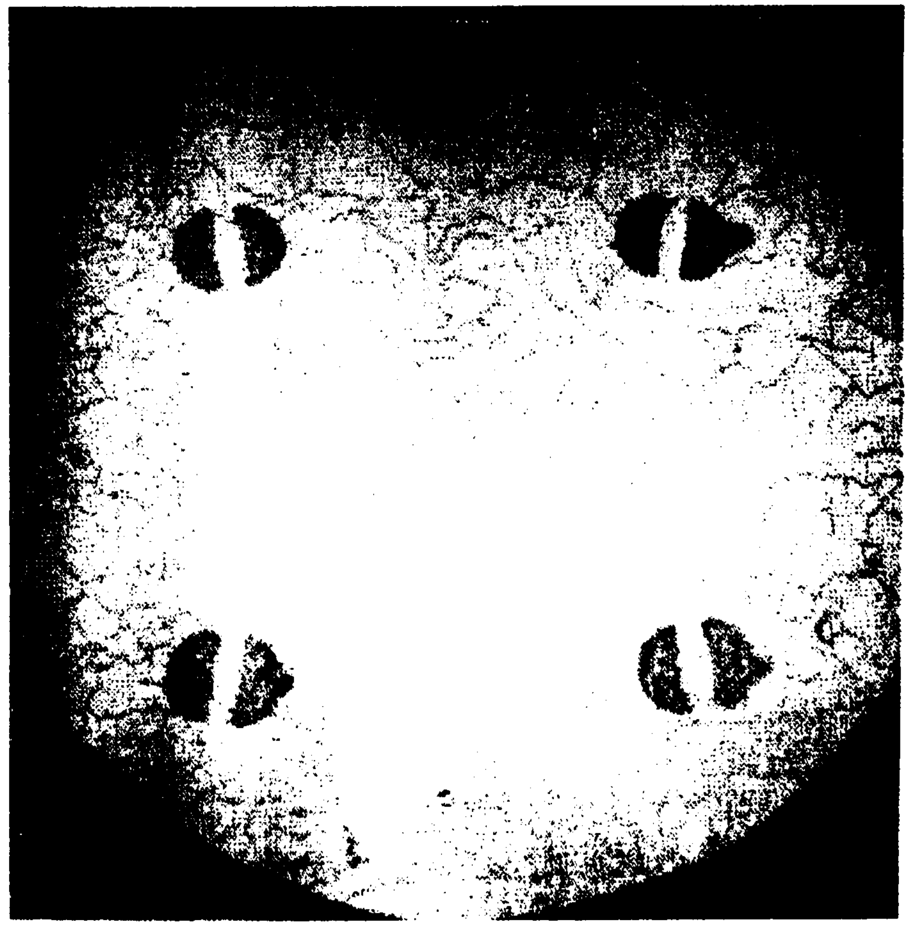
MOI in Use



Magneto-optic
eddy current image

Motivation

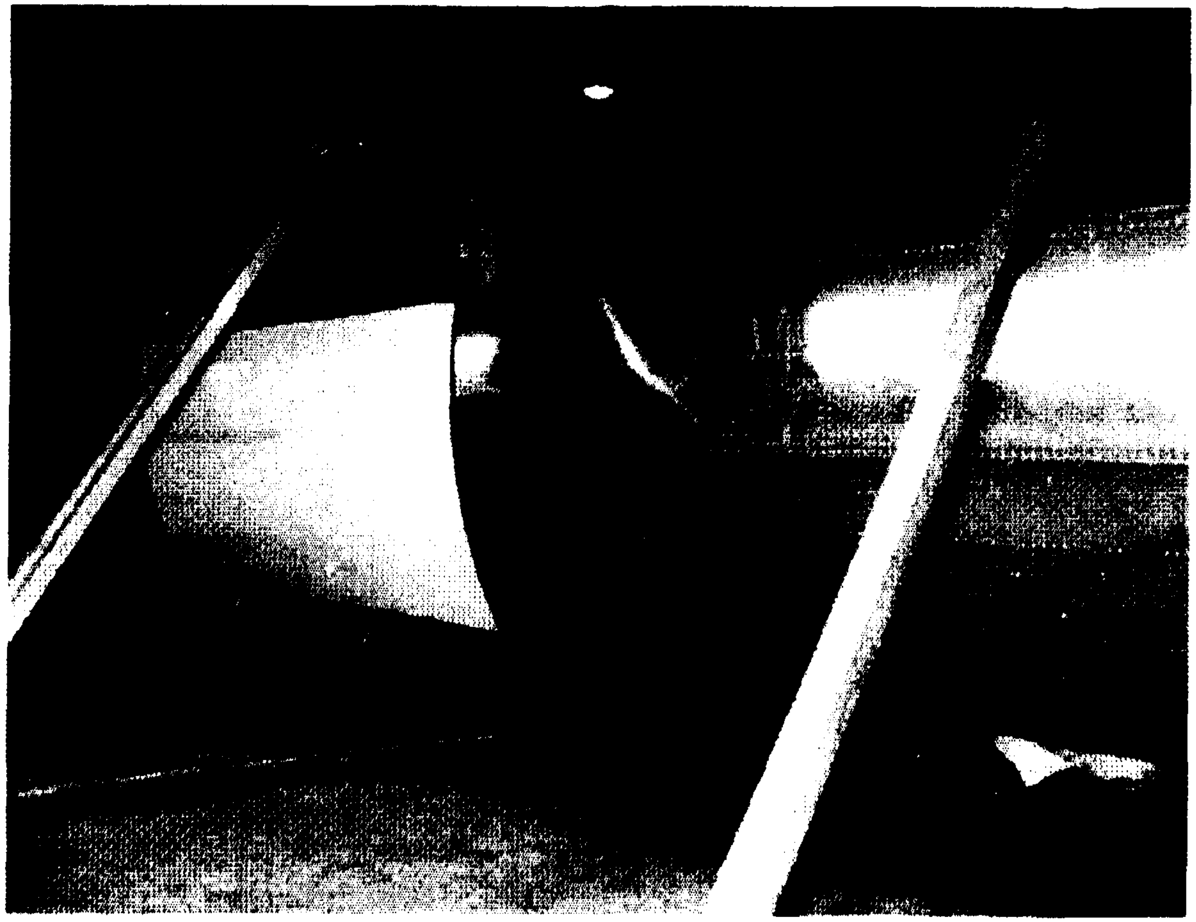
MOI is a fairly recent addition to available NDI techniques for surface crack detection. It is available for field use but has not realized wide-spread use. It is a good candidate for exercising FAA's Validation Process of characterizing NDI systems through field reliability assessments and cost-benefit analysis.

Skin Panels

Forty-three skin panels - 20 inch by 20 inch - 215 cracks - painted

Aircraft Panels

Two aircraft panels - one painted and one unpainted - 69 known cracks



Field Reliability Assessments

- Laboratory baseline data gathered
- Field Inspections were performed in conjunction with Eddy Current Inspection Reliability Experiment
  - Three facilities visited
  - Pre-Inspection MOI Training provided in two facilities where MOI was not in use

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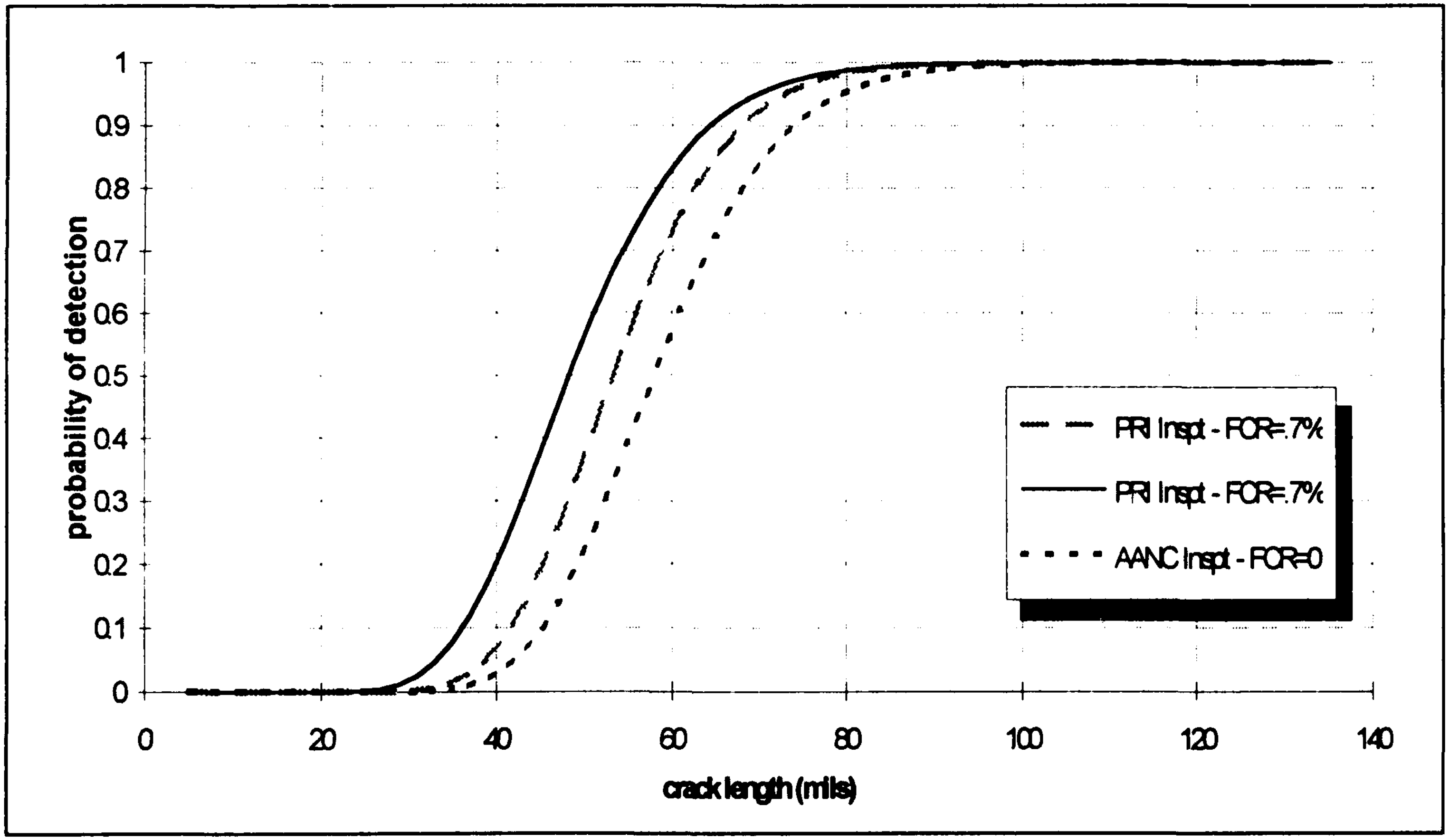
Probability of Detection Curves MOI



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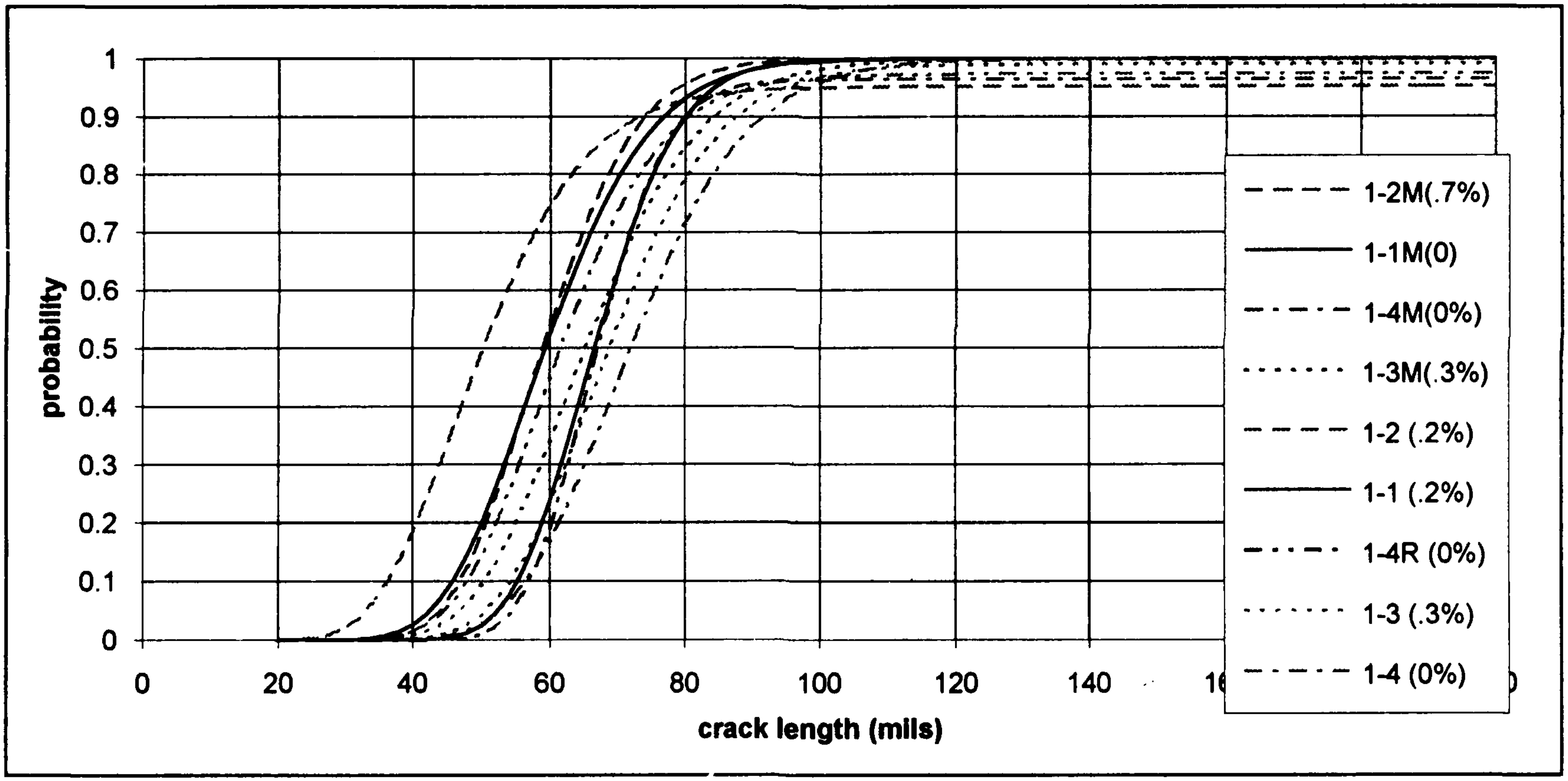
Individual PoDs - Facility 1



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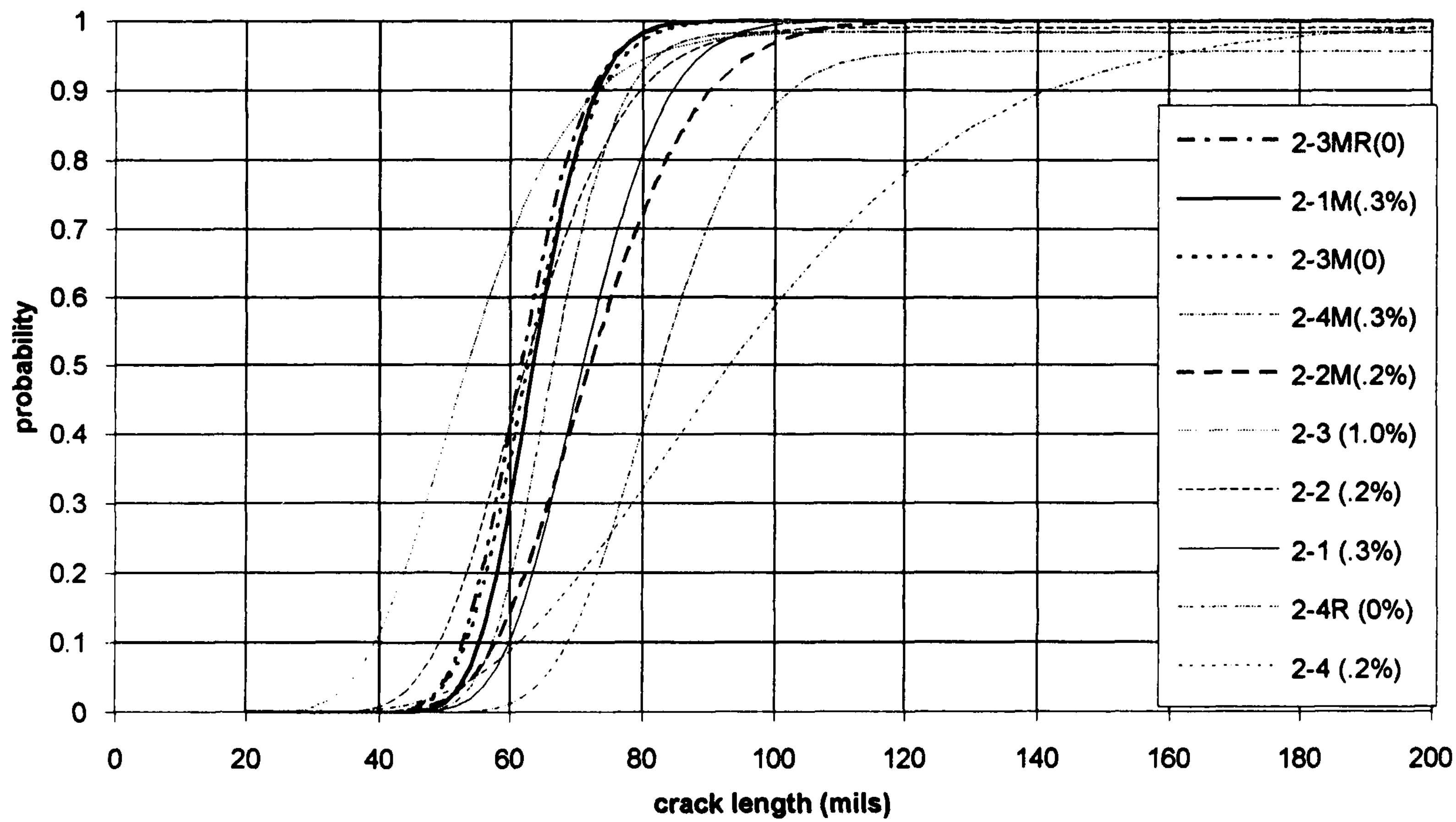
Individual PoDs - Facility 2



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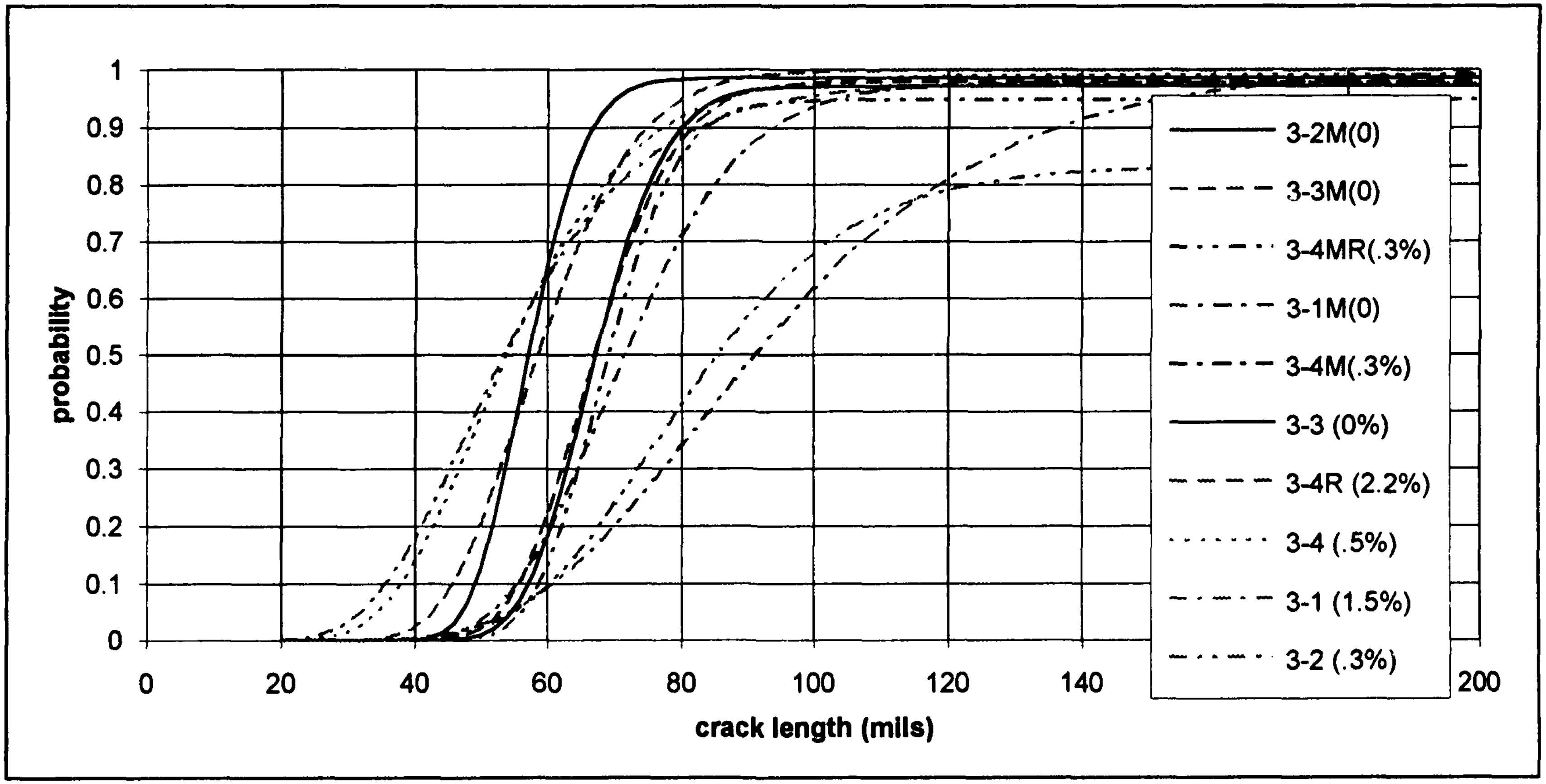
Individual PoDs - Facility 3



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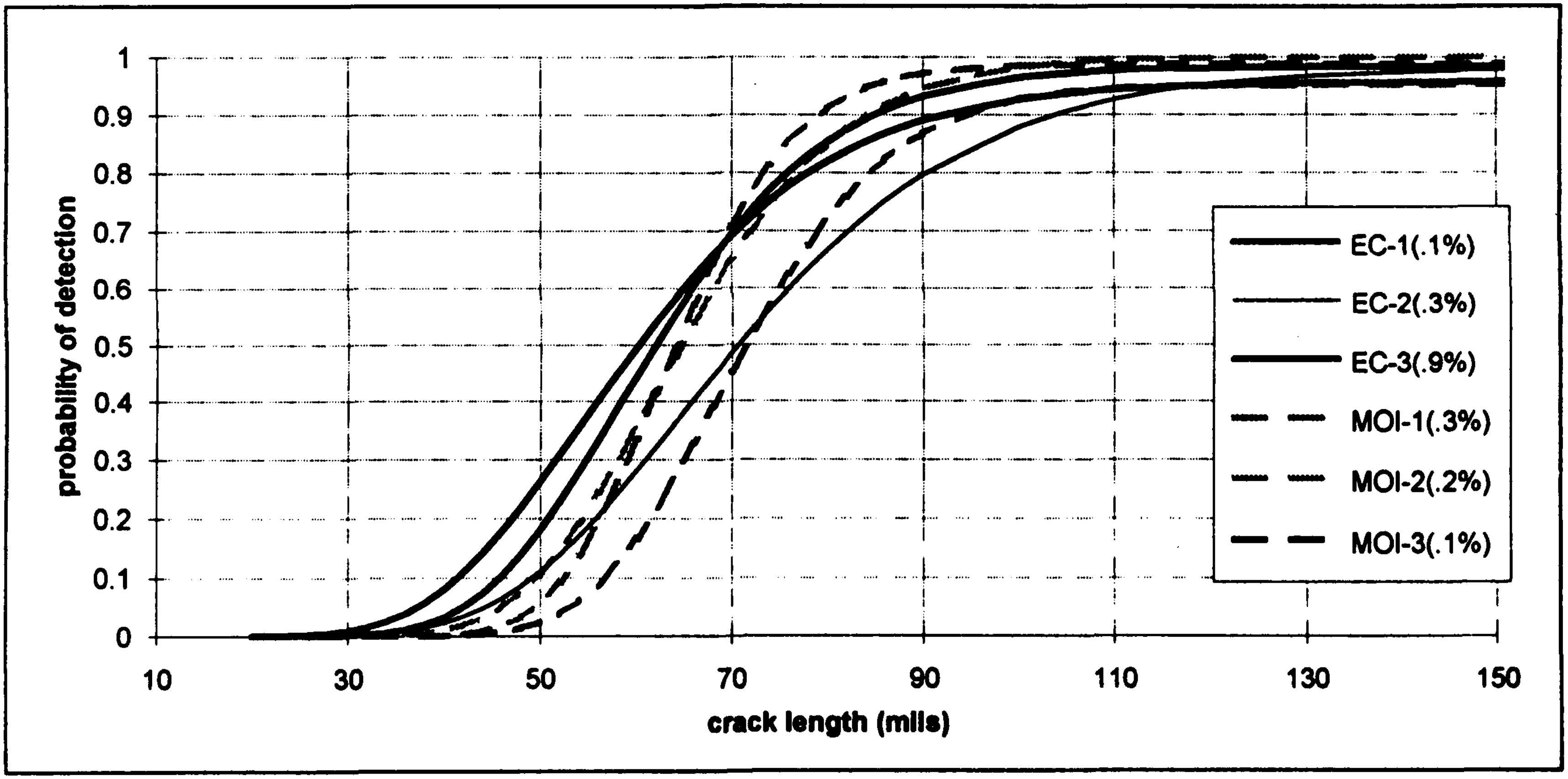
MOI - Eddy Current Comparison



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Average Inspection Times

Facility	EC	MOI
1	157	147
2	214	191
3	193	152

Times are in minutes

Observations

- Laboratory .9 PoD at = 69 mils
- Field degradation of 10 - 25 mils
- Improvements in reliability achievable
  - training with crack length feedback could improve capabilities
- Field reliability of MOI is comparable to EC techniques in use
  - inspection times shorter
  - training time less
- No reliability enhancement through redundant inspection as called for in Boeing procedures

Participation of the Transportation Center at Northwestern University in the Validation Process of Aging Aircraft NDI Technology in Conjunction with the AANC at Sandia National Laboratories

Title of Project: Application of Benefit-Cost Model and Techniques to NDI Methods for Aging Aircraft

Investigators: Aaron J. Gellman, Director, Transportation Center, Northwestern University

Vanessa J. Brechling, Research Analyst, Transportation Center, Northwestern University

Source of Funding: AANC

Technical Monitor: Dennis Roach

Time Duration: 5/1/93 - 4/30/94

Project Goal:	To develop and validate a cost-benefit anaysis addressing the reliability and cost-effectiveness of NDI techniques as applied to aging aircraft
Task Definition:	Develop general familiarity with the NDI process, especially its costs and expected uses
	Compare all costs associated with other approaches to the same problem
	Identify and acquire all data required for a cost-benefit analysis
	Produce cost-benefit analyses as necessary to advance technology

Deliverables:

1. Produce a relevant cost-benefit model to assess the net value of various NDI processes used in support of inspection and repair of aging aircraft.

2. Apply the model to NDI processes as they pass through the validation process at AANC, specifically to the Magneto-Optic Imager (MOI).

3. Develop a "how-to" handbook covering the model. This handbook will be used by persons who are familiar with the NDI process.

The Approach: Cost-Benefit Analysis

- Measurement of the costs and benefits of the NDI technique over the *life-cycle* of the investment
- Discounted by the appropriate rate
- Relative to a baseline scenario
- Cost-benefit analysis ≈ financial appraisal of an investment from the perspective of the firm
- Sensitivity analysis

NET PRESENT VALUE

$$NPV = B_0 - C_0 + \frac{B_1 - C_1}{(1+r)} + \frac{B_2 - C_2}{(1+r)^2} + \ldots \frac{B_t - C_t}{(1+r)^t}$$

WHERE

B = BENEFITS

C = COSTS

THESE ARE MEASURED AS AVOIDABLE AND INCREMENTAL

t = USEFUL LIFE OF THE TECHNOLOGY

r = DISCOUNT RATE

5

Data Requirements

Inspection Application:

- Types and location of structural flaws to be detected
- Limitations of breadth of use (including profile of fleet)
- Initial applications vs. routine use

Baseline Scenario:

- Existing methods of inspection for above applications

Costs:

- Capital Costs
- Operating Costs

Benefits:

- Decrease in Inspection Costs
  1) Shorter inspection times
  2) Less personnel required to perform inspection
  3) Systems designed for operation by personnel requiring less training
  4) Less dis-assembly of aircraft required (e.g., paint removal)
  5) Lower re-assembly costs after inspection
  6) Decrease in number of false positive detections
  7) Decrease in training costs
  8) Potential for decreased aircraft downtime

- Increased Probability of Detection

- Consumer Surplus: decreased cost of travel or improved safety is of value to the consumer

- External Benefits

- Long-run Benefits

Application of Model to the MOI

Inspection Application:	Crack detection on large, smooth surface areas of aircraft, especially useful for cracks emanating from rivet heads at lap joints. Possible gross corrosion detection on skin surface.
Baseline Scenario:	Traditional eddy current technology using the sliding probe device.
Costs:	Investment in Equipment Operating Costs: • faster inspections • less disassembly of aircraft required, i.e., no need to strip and re-apply paint • less training required

Benefits:	Increase in POD ??? Decreased operating costs as listed above

Types of Data Required

Data Source	Procedures	Reliability	Inspection Time	Training	Perceived Benefits
1. POD Experiment		✓✓✓	✓✓✓		
2. Industry Survey	✓✓✓	✓✓	✓	✓✓✓	✓✓✓
3. Documentation Review	✓✓✓		✓✓✓	✓	

✓✓✓ Primary Source
✓✓ important Source
✓ Auxiliary Source

Some Results from the Industry Survey:

- The procedures for which the MOI is useful are:
    - Lap-joint inspections on 27s, 37s, and 47s
    - Section 41 (flat side) skin inspection on 47s
- An alternate means of compliance is pending for application of the MOI on:
    - Crownskin inspections on the DC-10
    - Wing cover inspections on the DC-10
- Mixed response to the effectiveness of MOI for corrosion detection. Currently limited to gross surface corrosion.
- MOI does not replace any equipment or verification procedures
- Two people are generally required to perform inspections with the MOI
- MOI allows inspectors to perform their job more quickly because:
    - large areas can be inspected more quickly
    - less preparation of the aircraft is required

- There is a lot of variability in the amount of inspection time savings that the MOI can generate due to differences in the hangar environment.

- Some facilities are more easily able to take advantage of efficiency improvements than others. For example, some facilities cross-train visual inspectors or mechanics to help perform the MOI inspections.

- Training required for the MOI is much less than eddy current training, although most NDT inspectors have already completed eddy current training.

- Suggestions for improvement include:
  - better display projection/digitized display
  - lighter weight/smaller head
  - capability to inspect over surface protrusions and curvature
  - heads-up display/single inspector capability
  - attachment probe to go into rivet holes
  - battery operate/improve accessibility
  - ability to detect corrosion and second layer flaws

Some Results from the POD Experiment:

- Inspections of the sample panels were completed 20% more quickly with the MOI than with the sliding probe

  - Inspector experience was found to be positively related to the time savings generated by using the MOI for inspections

- Reliability is not significantly different between the MOI and the sliding probe

  - POD rates show no improvement for inspections with the MOI

- Ability to find smaller cracks is not significantly increased or decreased with the MOI

- The reliability and inspection times of the MOI for one-person inspections are not significantly different than those for two-person inspections.

Some Results form the Documentation Review:

- For the most part, the 27 and 37 lap splice HFEC inspections for which the MOI has been used have been terminated by replacing the original rivets with button head rivets.

- The 47 upper lobe skin lap HFEC inspection is required according to the following data:

Effectivity:	line numbers 001 - 200
Commencement:	prior to 15,000 accumulated landings (approx. 20 years)
Frequency:	4,000 landings (forward of BS 1000) 6,000 landings (aft of BS 1480)
FAA Estimate:	56 man-hours 14 elapsed hours
# Major Carriers:	5
Avg. # Planes:	12
Avg. Age	18.6 years

- The 47 upper body skin HFEC inspection on the flat-side in Section 41 is required according to the following data:

Effectivity:	line numbers 001 - 430
Commencement:	prior to 12,000 accumulated landings (approx. 16 years)
Frequency:	2,000 landings
FAA Estimate:	24 man-hours 12 elapsed hours

# Major Carriers:	5
Avg. # Planes:	19
Avg. Age	18.6 years

Terminating modification is required for airplanes line numbers 001 - 200 prior to the accumulation of 20,000 landings (approximately 27 years in-service). The modification consists of replacing the skin panel with a new improved panel.

- The DC-10 applications have not yet been verified, but it can be foreseen that a number of carriers will be greatly effected by this.

# Major Carriers:	4
Avg. # Planes:	39
Avg. Age	16.9 years

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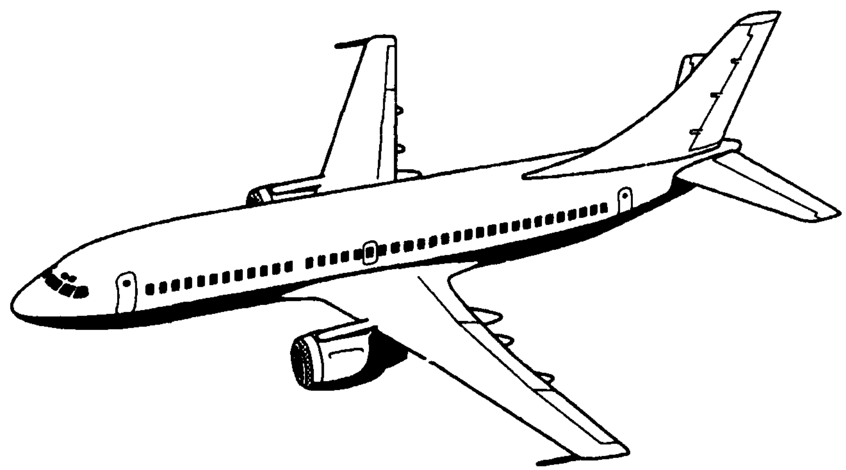
Assessment of Eddy Current Inspection Equipment



Floyd W. Spencer
AANC

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Inspection Reliability Experiments

Goals:

- Provide reliability assessments of eddy current inspection equipment and processes used in crack detection applications.
- Encourage equipment maturation through quantitative reliability feedback to developers of equipment

Common Basis for Reliability Experiments

- Use of AANC available test specimens
- Well characterized cracks
  - distribution of crack lengths
  - varying angles and locations
  - lengths are unknown to experimenter
- "Laboratory" (tabletop) inspections
  - human variation not reflected

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Skin Panels

Forty-three skin panels - 20 inch by 20 inch - 215 cracks - painted

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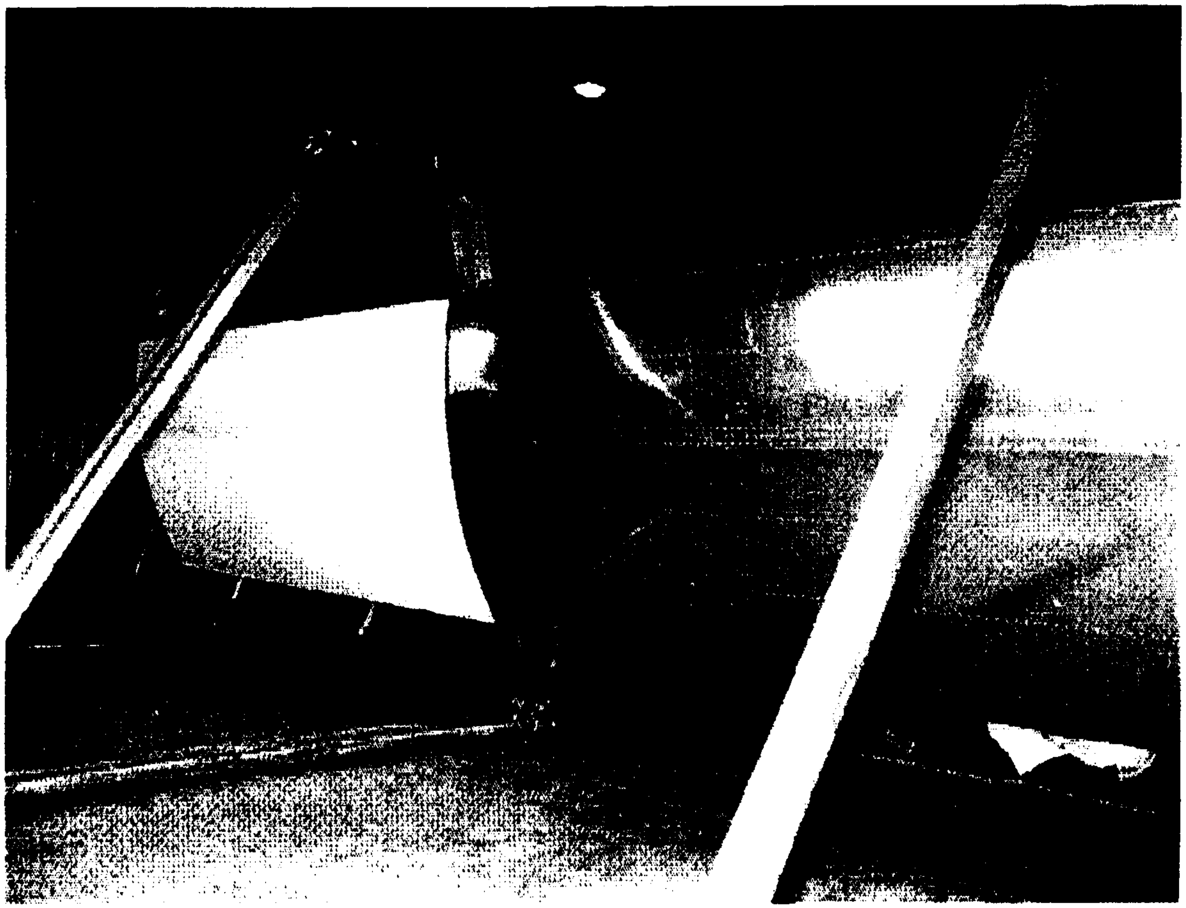
Aircraft Panels

Two aircraft panels - one painted and one unpainted - 69 known cracks



Reliability Experiment Participants

- Nortec-30 Eddyscan System (Staveley Instruments)
- Magneto-Optic/Eddy Current Imager (PRI Instrumentation)
- Low Frequency Eddy Current Array / LFECA (Northrop)
- Current Array Imaging System(Boeing)

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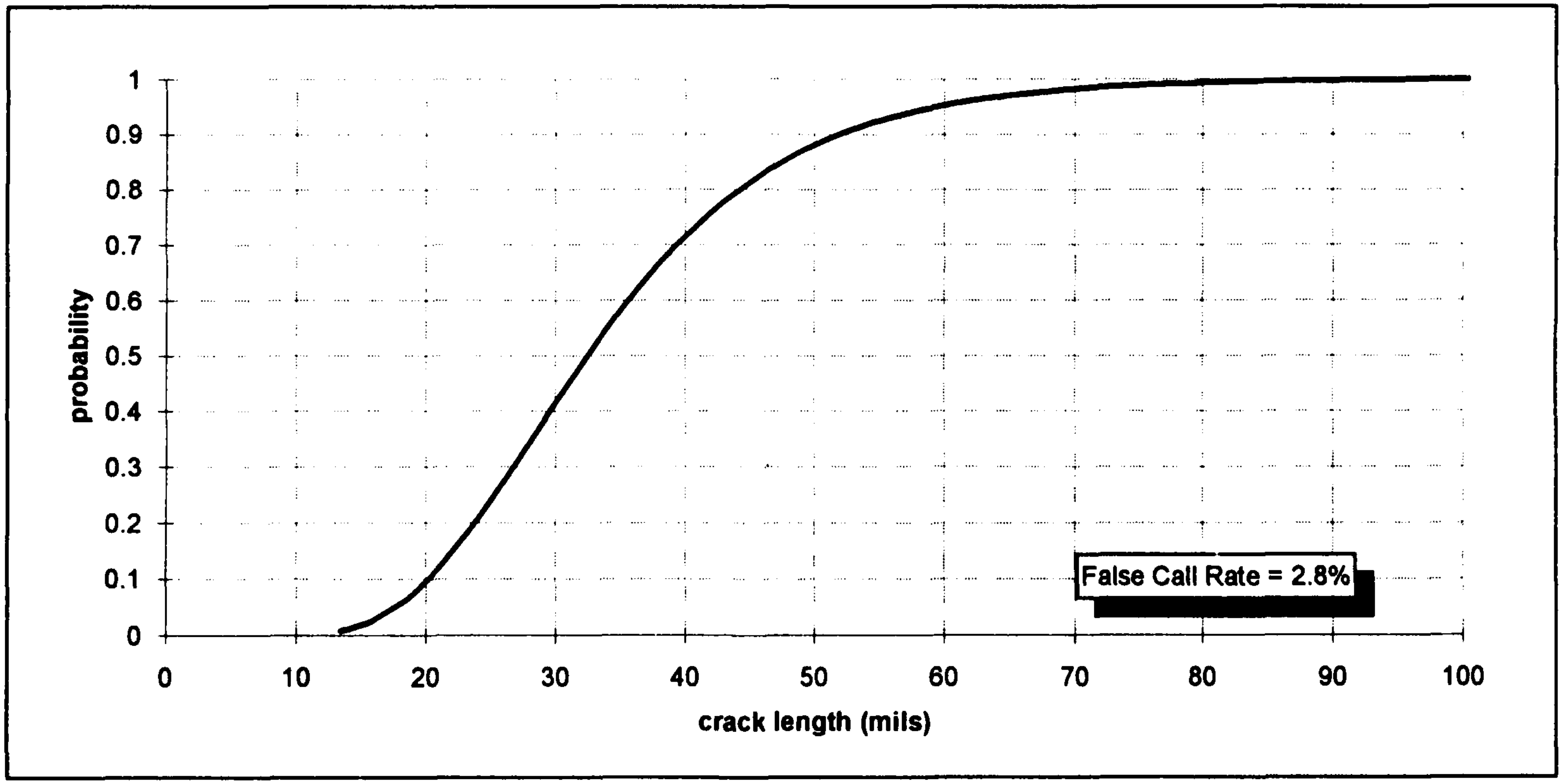
Probability of Detection Curves - Nortec 30 Eddyscan System



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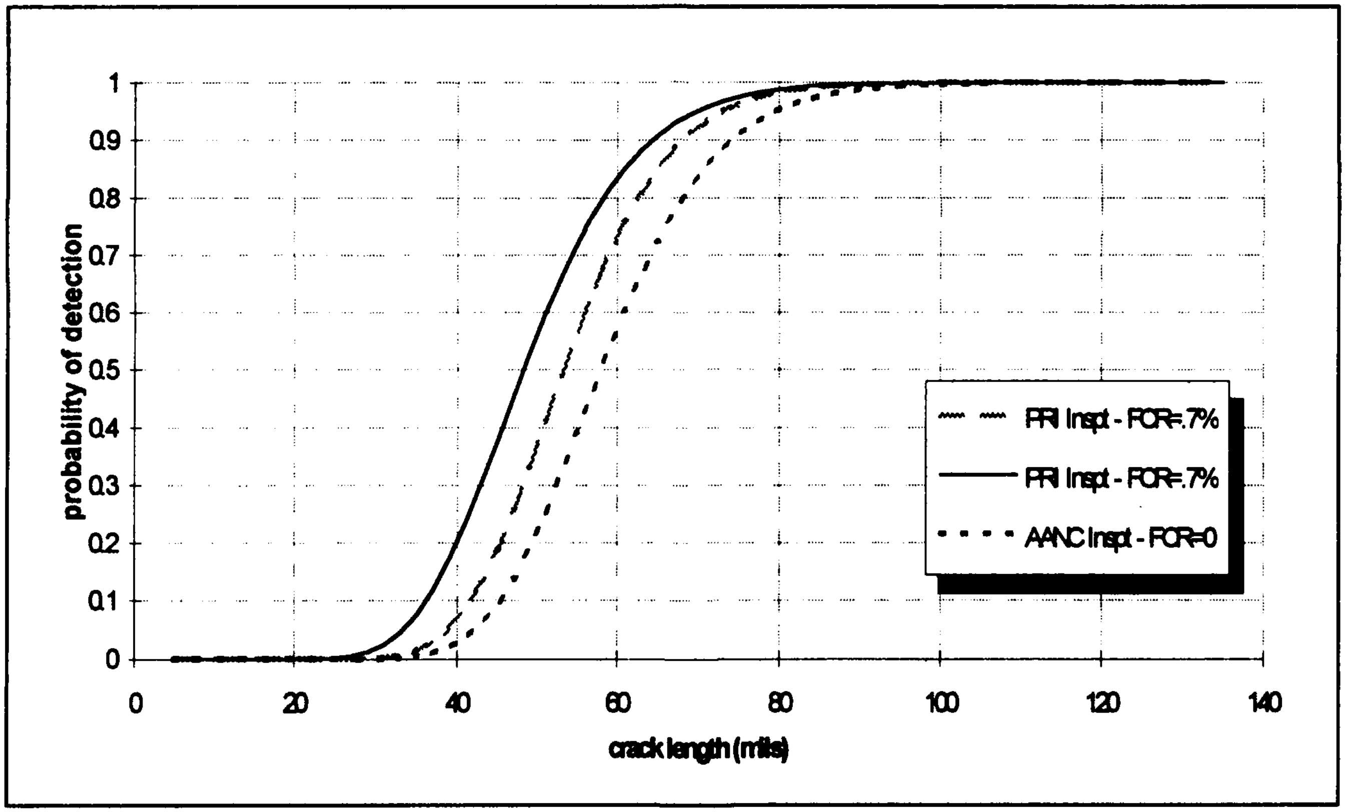
Probability of Detection Curves MOI



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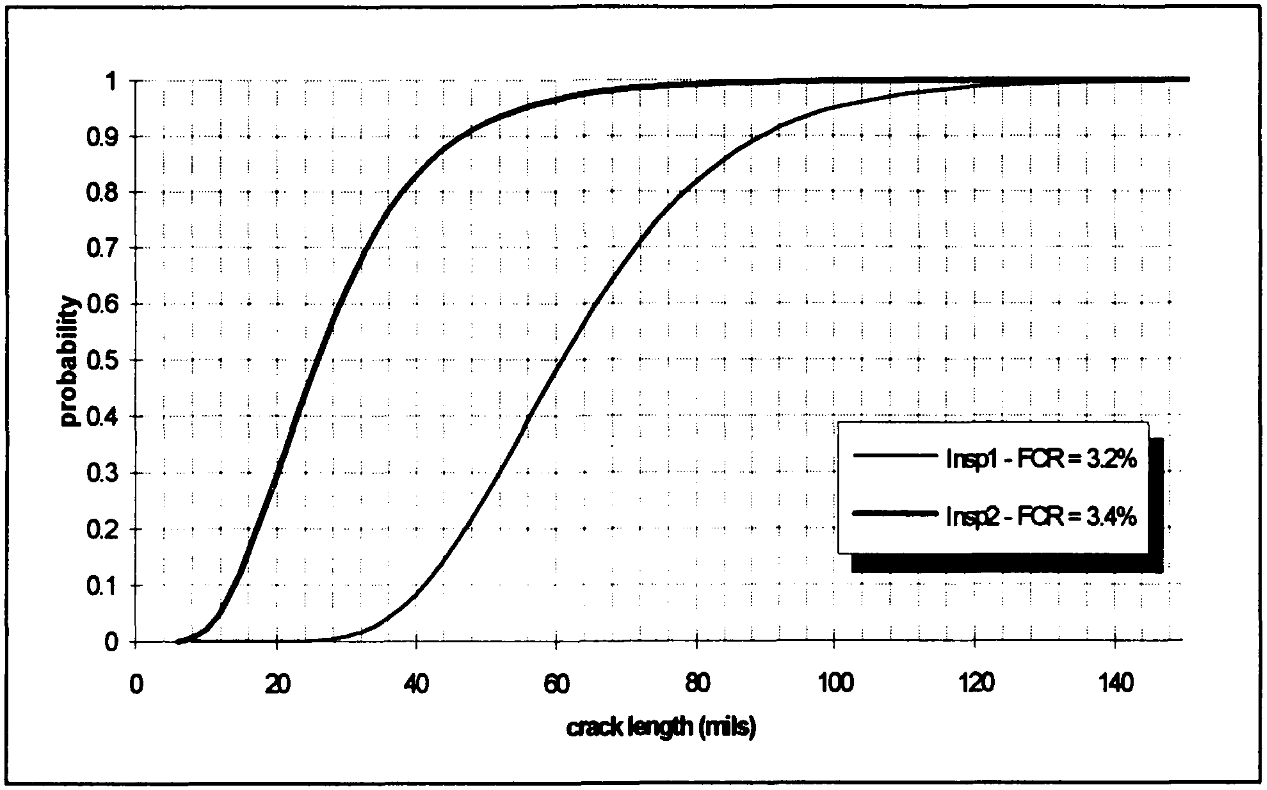
Probability of Detection Curves LFECA



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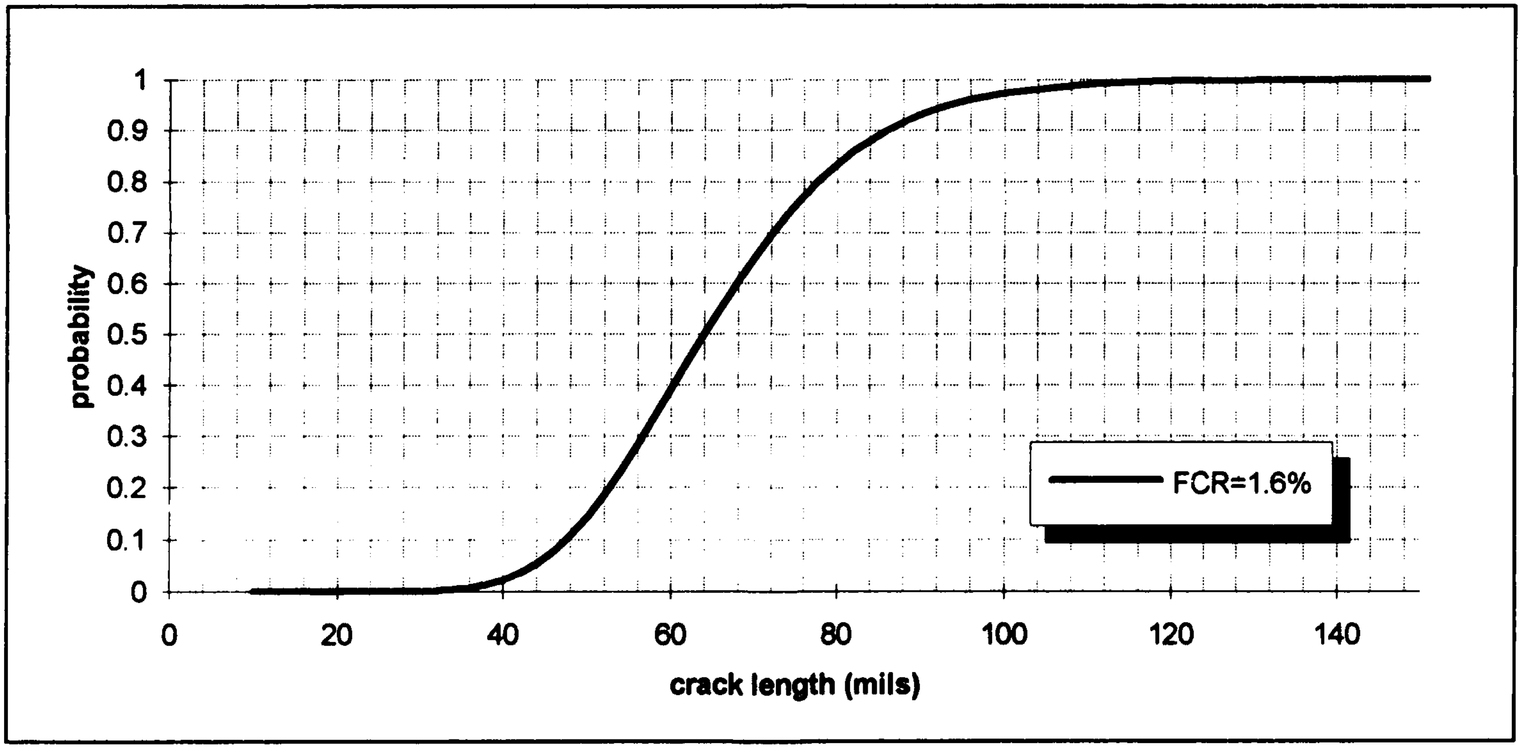
Probability of Detection - Current Array Imaging System



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Limitations & Benefits of Reliability Experiments

- Limitations
  - usually performed by developer or other "well-trained" individual - doesn't incorporate variation in performance among individuals
- Benefits
  - Provides information to potential users as to the capabilities of equipment in the marketplace
  - Assists new ideas to enter the marketplace by aiding equipment and procedure maturation

Evaluation of Scanners for C-Scan Imaging in Nondestructive Inspection of Aircraft

William Shurtleff
Principal Investigator: John Gieske
AANC

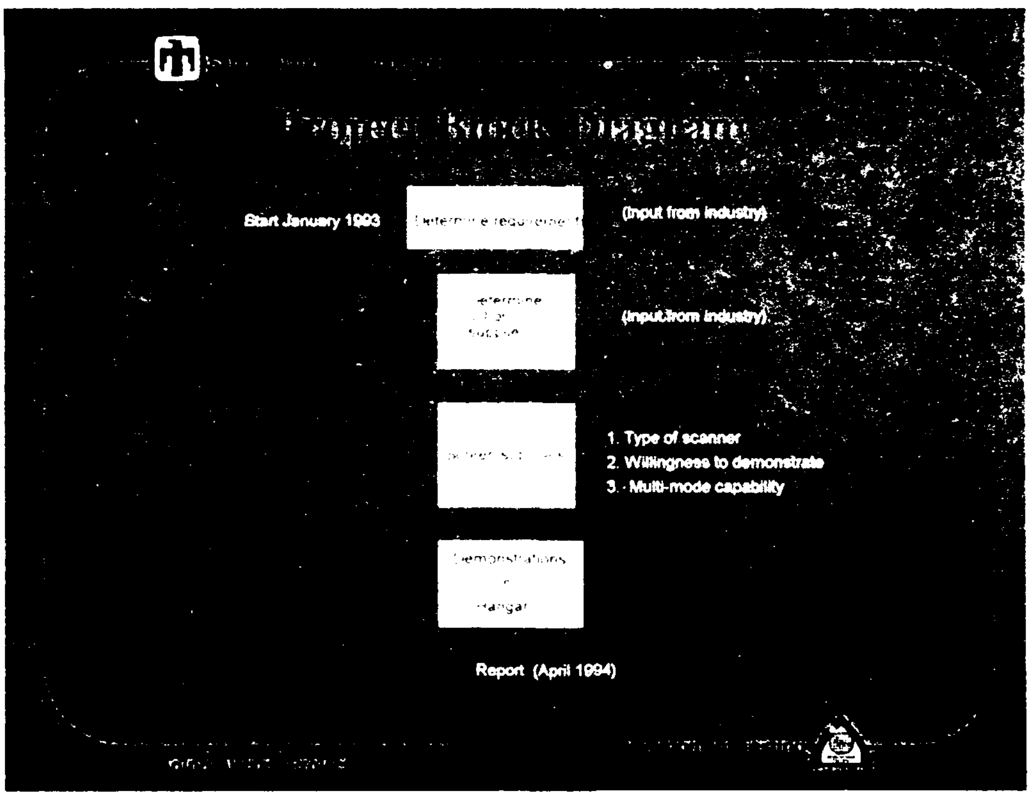
- Imaging systems have advantages over single point inspection systems in the areas of signal interpretation and documentation of results
- The U. S. aircraft industry has expressed considerable interest in using scanning systems for field inspection
- There have been claims by scanner manufacturers about ease-of-use and reliability of their scanners for field inspection of aircraft

Goal: **Demonstrate and Evaluate suitable commercial computerized systems for eddy current and ultrasonic inspections with manual, semi-automated, and automated scanners for aircraft NDI applications**

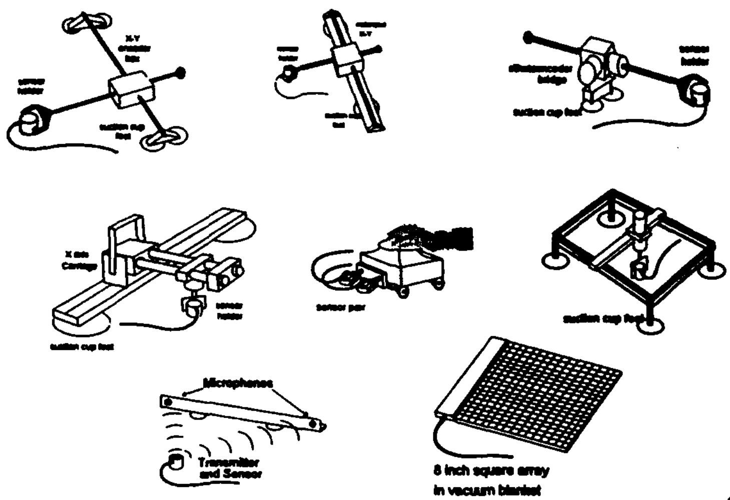
Demonstrate ⇧ performance capabilities, limitations, costs, speed, skill, training etc

Evaluate ⇧ rate performance using a set of performance criteria

Report ⇧ demonstration data, evaluations, and recommendations for improvement



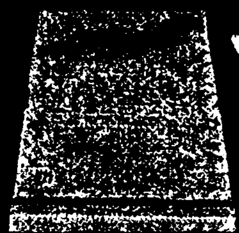
Scanner Systems



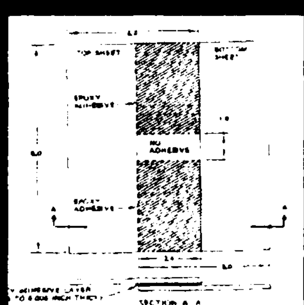
List of Participating Vendors

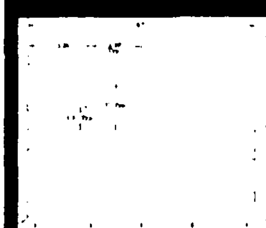
Vendor	Ultrasonics	Eddy Current	Scanner Type	Visits
Krautkramer Branson	Yes	Yes	Manual, radial axis	2
Dupont	Yes	Yes	Automated, tilting arm	1
ABB Amdata	Yes	Yes	Automated, cantilever arm	1
Matec/Sonix	Yes		Manual, tilting arm	1
SAIC Ultraimage	Yes	Yes	Manual and automated; cantilever arm	2
Infometrics	Yes	Yes	Manual, tilting arm	2
Smart-Eddy Systems		Yes	Manual; sound source	1
McDonnell Douglas	Yes	Yes	Semi-automated, hand-held	1
Panametrics	Yes		Automated; rigid x-y rectangular	1
Sierra Matrix	Yes		Semi-automated, tilting t-bar, heads-up	1
Failure Analysis Associates	Yes		Automated, electronic array	1

- A. D. Little aluminum lap splice joint with intergranular corrosion
- Large aluminum panel with visible pitting and intergranular and exfoliation corrosion



- Calibration standards for circumferential tear strap disbond test
- Boron/epoxy composite repair sample with implanted disbonds and delaminations on an aluminum skin
- Various locations on the B737 aircraft





- Calibration and initial setup using flat samples on table
  - Eddy current scan on the A. D. Little samples
  - Eddy current scan on large panel
  - Ultrasonic pulse echo and resonance on the calibration standards and the boron/epoxy repair
- Scans on various parts of aircraft

Date 4/8/94

Evaluation Criteria

- 27 Evaluation Criteria

<u>Design</u>
Basic design and scan motion
Mount type
Probe holder and gimbals design
Couplant feed
Scanner working distance
X-Y axis resolution

<u>Portability</u>
Scanner weight
Ruggedness
Deployment ease
Computer hardware
Motor controller

<u>Articulation</u>
Complex shapes
Surface conditions

<u>Performance</u>
Speed of coverage
Accuracy
Problems

<u>Usability</u>
Easy of scan
Vertical clearance needed

<u>Software</u>
Ease of use
Ease of parameter setup
Data acquisition characteristics
Image display
Image and data processing
Hard copy
Operator training
NDI modes supported

<u>Cost</u>

	Rating	Explanation
	1	Not applicable for aircraft applications
	2	Limited for aircraft applications
	3	Adequate but could be improved for aircraft applications
	4	Good, generally applicable for aircraft applications
	5	Ideal, meets all requirements for aircraft applications
Mount Type		Implementation, relocation ease, stability
	1	Not stable, fails often during scan
	2	Fails occasionally during scan
	3	Adequate but could be improved for aircraft applications
	4	Good generally applicable for aircraft applications
	5	Ideal, meets all requirements for aircraft applications
Deployment Ease		Time from off the shelf to start of scan or relocation
	1	Greater than 1 hour
	2	Between 30 to 60 minutes
	3	Between 15 to 30 minutes, 5 minutes relocation
	4	Between 10 to 15 minutes, 2 minutes relocation
	5	Under 10 minutes, 1 minute relocation

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Evaluation Matrix Example

Features and Factors \ Company and Scanner	Krautkramer Branson Horking ANDSCAN	DuPont CalData Zetec PORTASCAN	ABB Amdata AMAPS	MATEC SONIX HANDLSCAN
DESIGN				
Basic Design and Scan Motion	$\boxed{4}$ Tilting Radial Arm With circular motion Manual &Random	$\boxed{4}$ Tilting Arm Bridge With X-Y linear motion Automated	$\boxed{3}$ Cantilever Arm with Rigid X-Y linear motion Automated	$\boxed{3}$ Tilting Arm Bridge With X-Y linear motion Manual &Random
Mount Type	$\boxed{3}$ Three suction cups in series with one hand vacuum pump	$\boxed{4}$ Three independent suction cups with three manual vacuum pumps	$\boxed{2}$ Numerous suction cups in series, one AC vacuum pump	$\boxed{3}$ Static rubber suction cups without manual vacuum pumps
Probe Holder and Gimbals Design	$\boxed{5}$ Excellent	$\boxed{4}$ Good	$\boxed{4}$ Good	$\boxed{3}$ Adequate
Couplant Feed UT only, NA for ET	$\boxed{5}$ Water drip feed at fluted probe holder	$\boxed{5}$ Water drip feed at fluted probe holder	$\boxed{5}$ Water drip feed at probe holder	$\boxed{2}$ Manual spray or wipe on with cloth
Scanner Working Distance Height	$\boxed{4}$ Minimum 10 inches	$\boxed{4}$ Minimum 10 inches	$\boxed{3}$ Minimum 12 inches	$\boxed{4}$ Minimum 6 inches
X-Y Axis Resolution	$\boxed{5}$ 0.012 inch	$\boxed{5}$ 0.01 inch	$\boxed{5}$ 0.01 inch	$\boxed{5}$ 0.005 inch

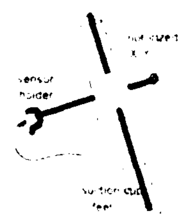
Aging Aircraft Project

Development Testing

- ✓With proper calibration, quantitative measurements can be made of hidden corrosion and disbonds using scanners
- ✓Surface scratching with the automated scanners was a problem
- ✓Eddy current measurements were easier to obtain than ultrasonic measurements
- ✓Use manual scanners mostly for small areas
- ✓Passive rubber cup suction feet are unreliable
- ✓The dual axis tilting arm and bridge provided the best overall results of the automated scanners
- ✓The radial axis tilting arm with rotation axis provided the best overall results of the manual scanners

Sandia National Laboratories

Date 4.7.94



dual axis tilting arm and bridge

radial axis tilting arm with rotation axis

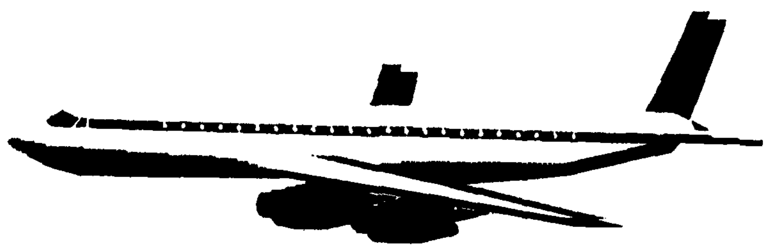
Aging Aircraft Project

Development Testing

- Use table information to compare scanners for a particular application
- See examples of flaws detected by C-scan NDI techniques
- Read about lessons learned during the demonstrations

- Add information as more scanners come into the validation center for demonstration
- Provide consultation on applications
- ?

Tech Transfer Process and Its Implementation on DC9 Wing Box

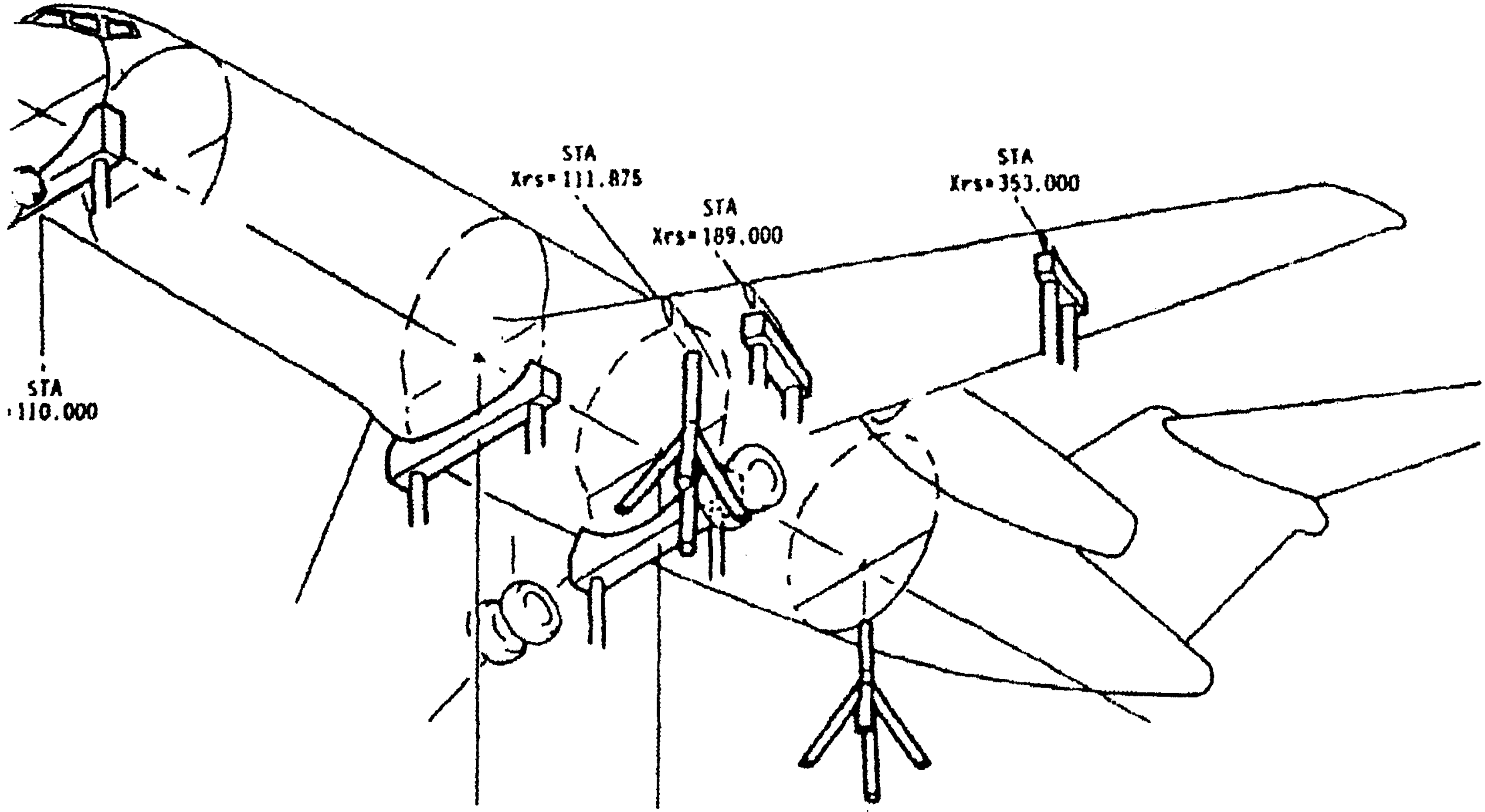


Mike Ashbaugh
AANC (SAIC)

Overview

- Validation Process
- Proposed UT Probe Solution
- DC9 Wing Box (SB 57-98)
- Progress to Date
- Planned Activities

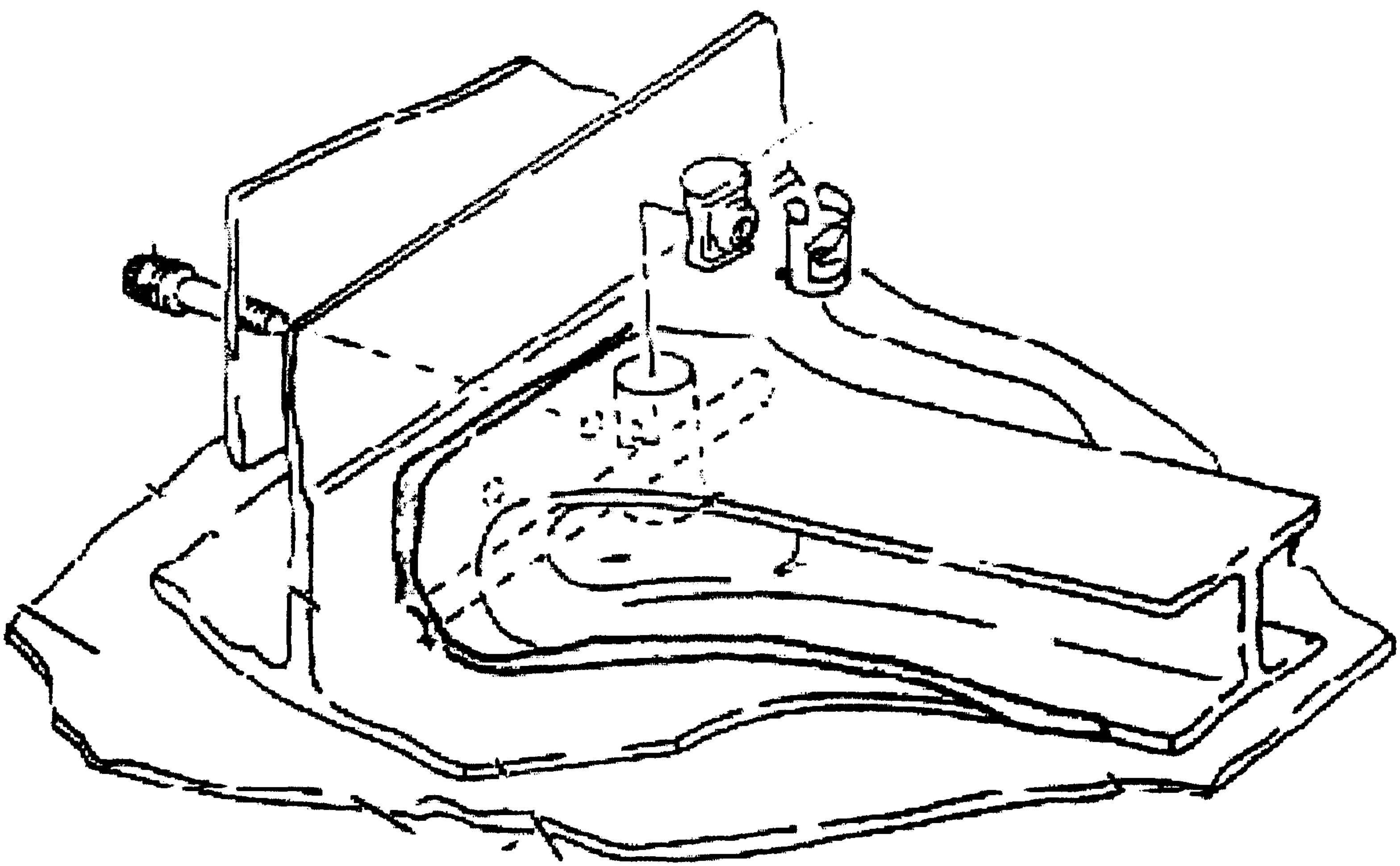
DC9 Wing Box (SB 57-98)



Sandia National Laboratories

Date: 3/31/94

DC9 Wing Box (SB 57-98)



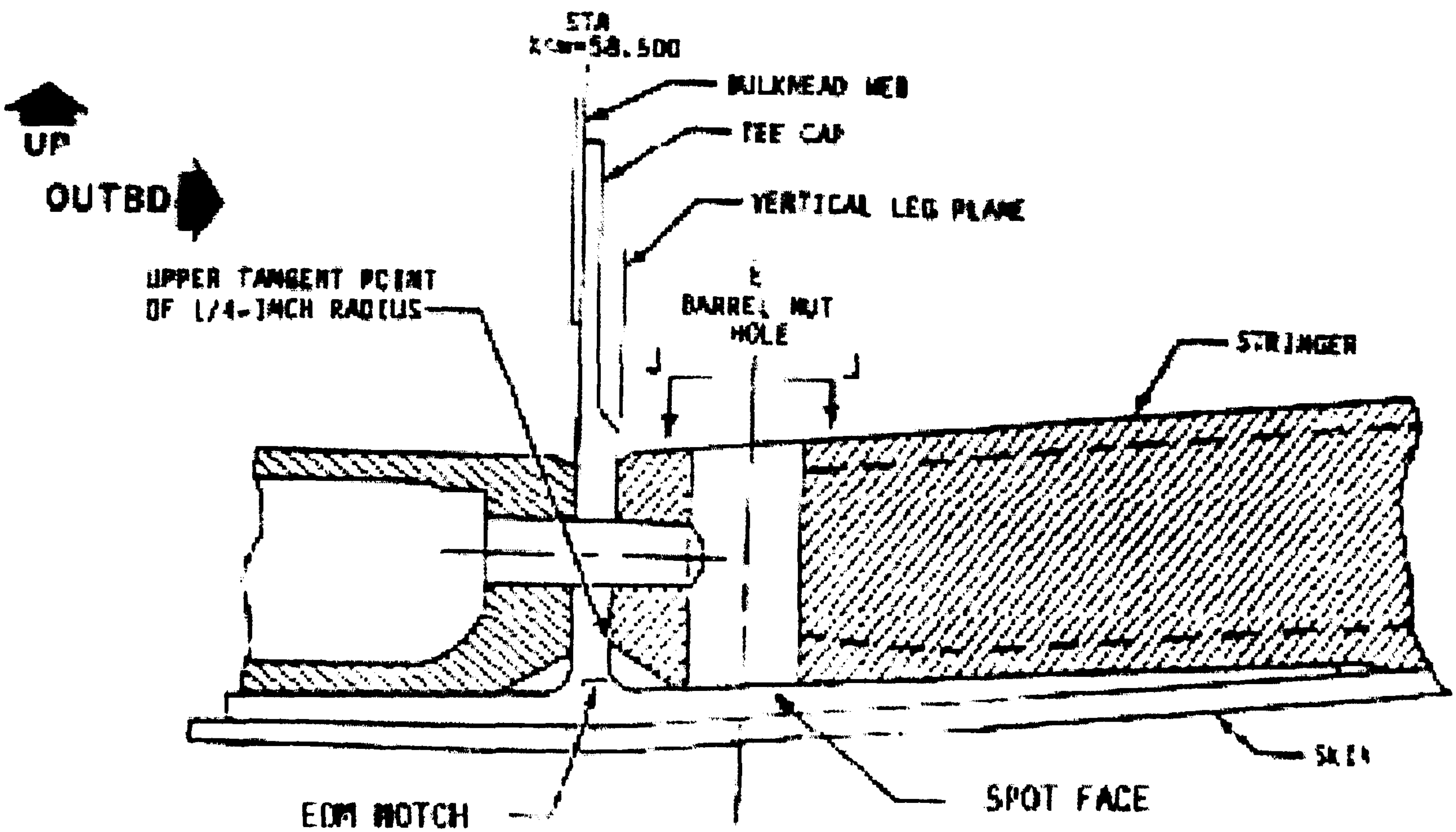
Department 2757, Aging Aircraft Project

Development Testing

Date: 3/31/94

Sandia National Laboratories

DC9 Wing Box (SB 57-98)



Development Testing

Department 2757, Aging Aircraft Project

Progress To Date

- Laboratory Development at Northwestern University
  - Fabricated sample at Northwest Airlines
  - DC9 wing box cut out
  - DC9 wing box cut out with induced flaws
- Interaction with McDonnell Douglas *(Feb. 25/March 30)*
- Coordination Meeting *(March 14)*
  - AANC, Northwestern University, Northwest Airlines, Weber Technologies
- Integration of SAIC Ultra Image Processing *(March 29)*
- Planning Meeting *(March 30)*
  - AANC, CASR, Northwestern University, SAIC, Weber Technologies, McDonnell Douglas, Northwest Airlines

Planned Activities

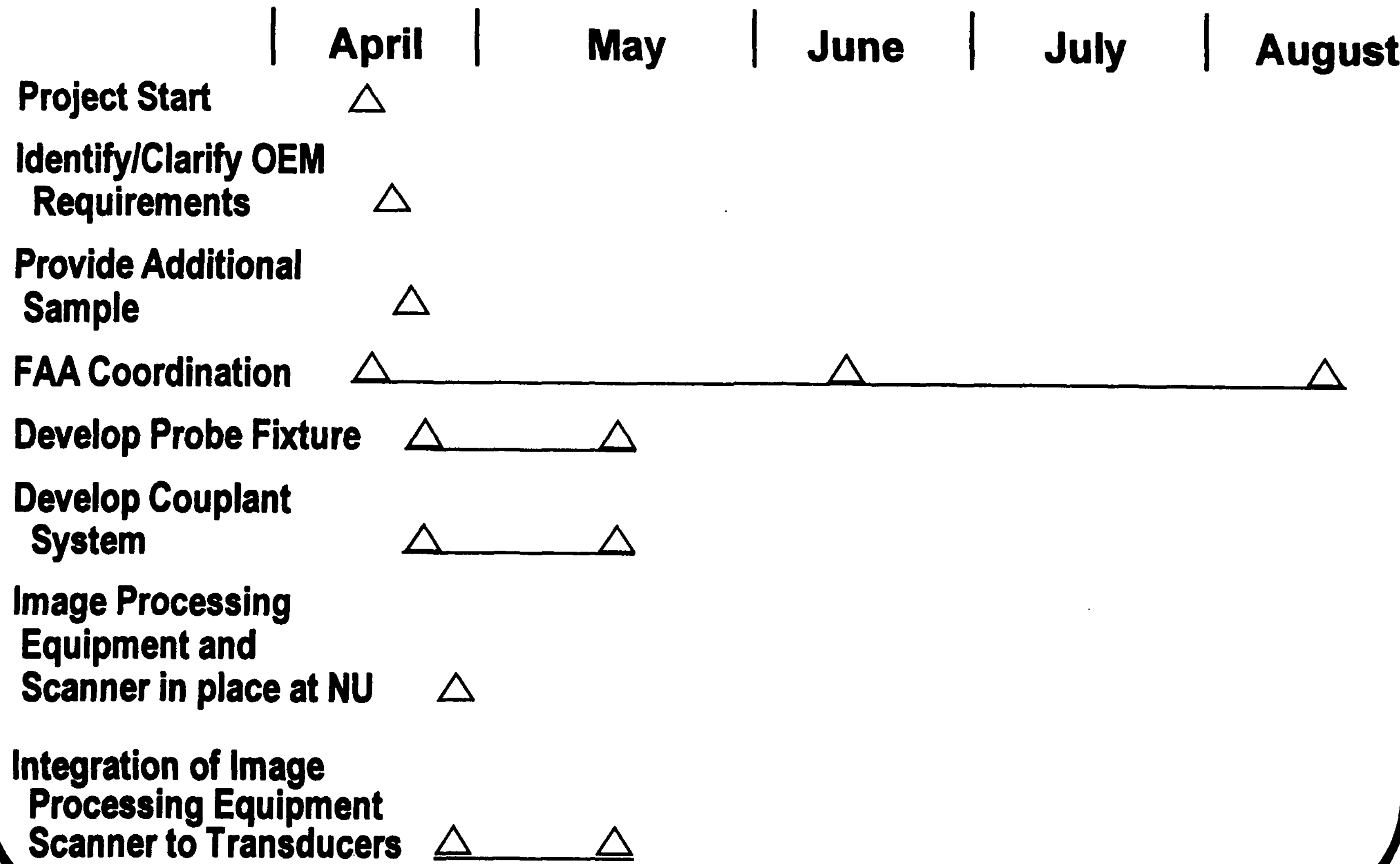
Major Milestones

- Laboratory Demonstration - quantification of second layer thinning
- Laboratory Demonstration - integration of fixture, image processing, scanning device, etc.
- On Aircraft Prototype Demonstration

Sandia National Laboratories

Date: 3/31/94

Scheduled Planned Activities

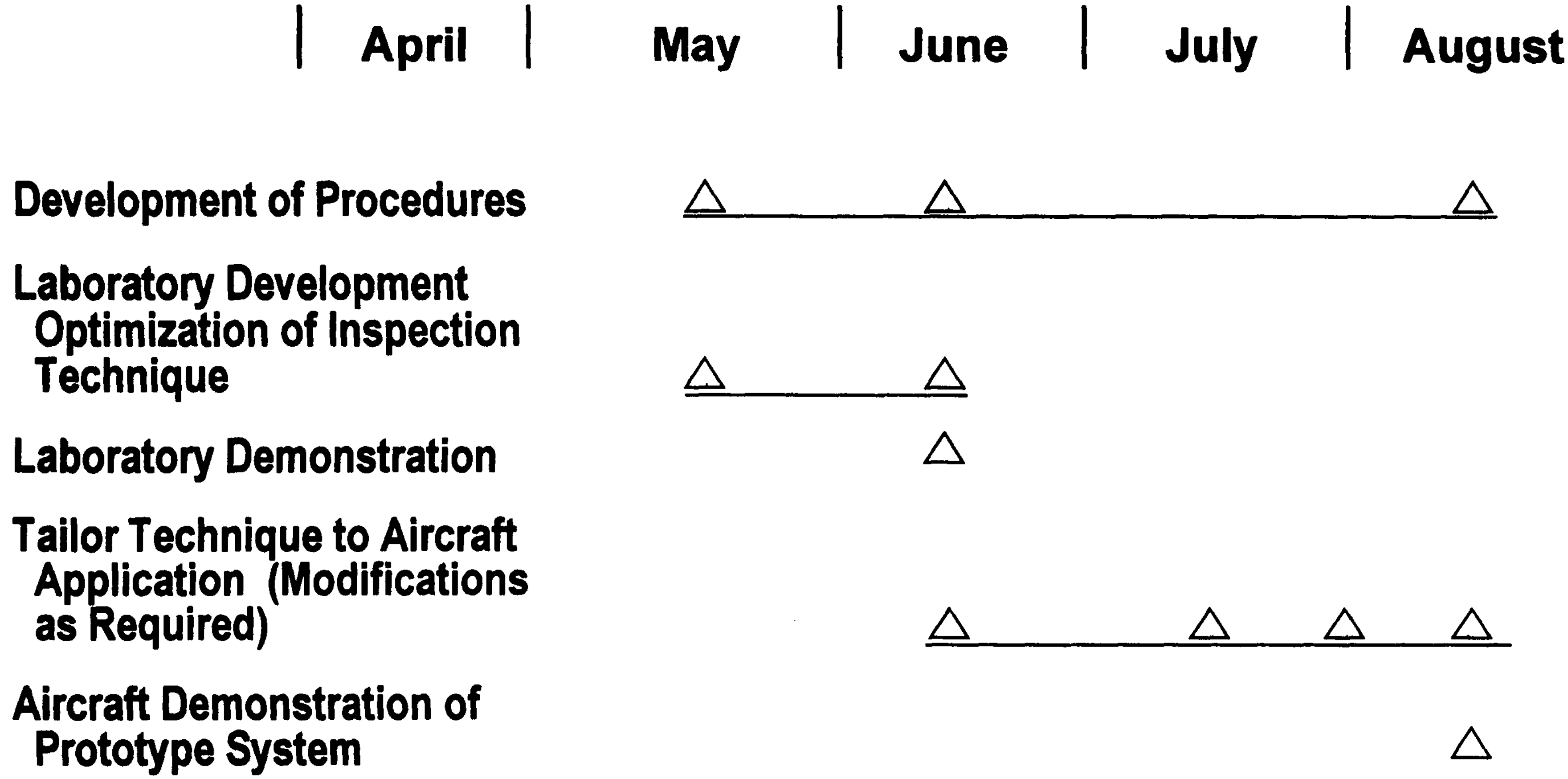


Development Testing

Department 2757, Aging Aircraft Project

Sandia National Laboratories

Scheduled Planned Activities



Development Testing

TECHNOLOGY TRANSFER

ULTRASONIC INSPECTION OF DC-9 WINGBOX

OBJECTIVES

Detection and characterization of material corrosion loss and stress corrosion cracks in multi-layered airplane structures.

APPROACH:

Detection of corrosion in DC-9 Tee Cap with ultrasonic inspection being accomplished from outside wing skin surface.

Quantitative characterization of material corrosion loss.

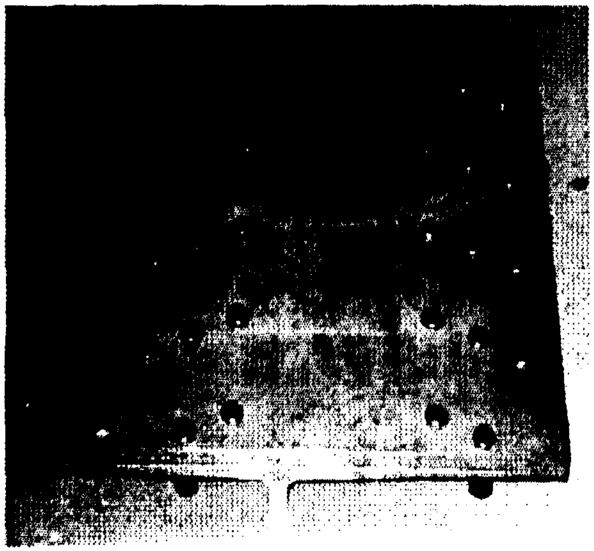
Detection of corrosion cracks and stress corrosion cracks in DC-9 Tee Cap.

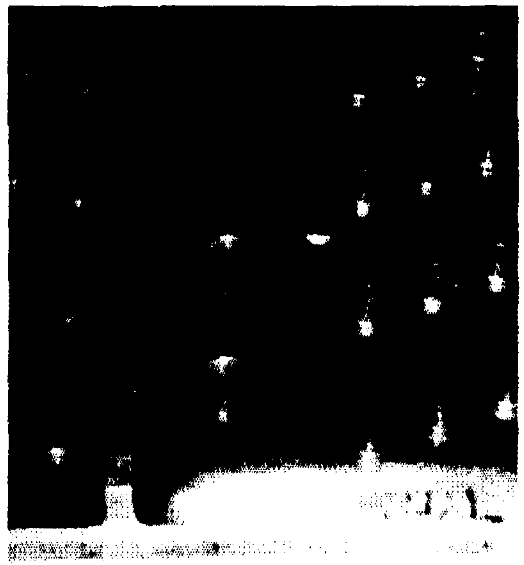
Development of the transducer fixture and the scanner for contact ultrasonic inspection.

Development of a computerized system for data acquisition and imaging.

Sample #1 is a standard specimen with machined spot faces and EDM notches.

- Sample #1 from Northwest Airlines





CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION

DC-9 STA[illegible] STD

MFG MATCHING

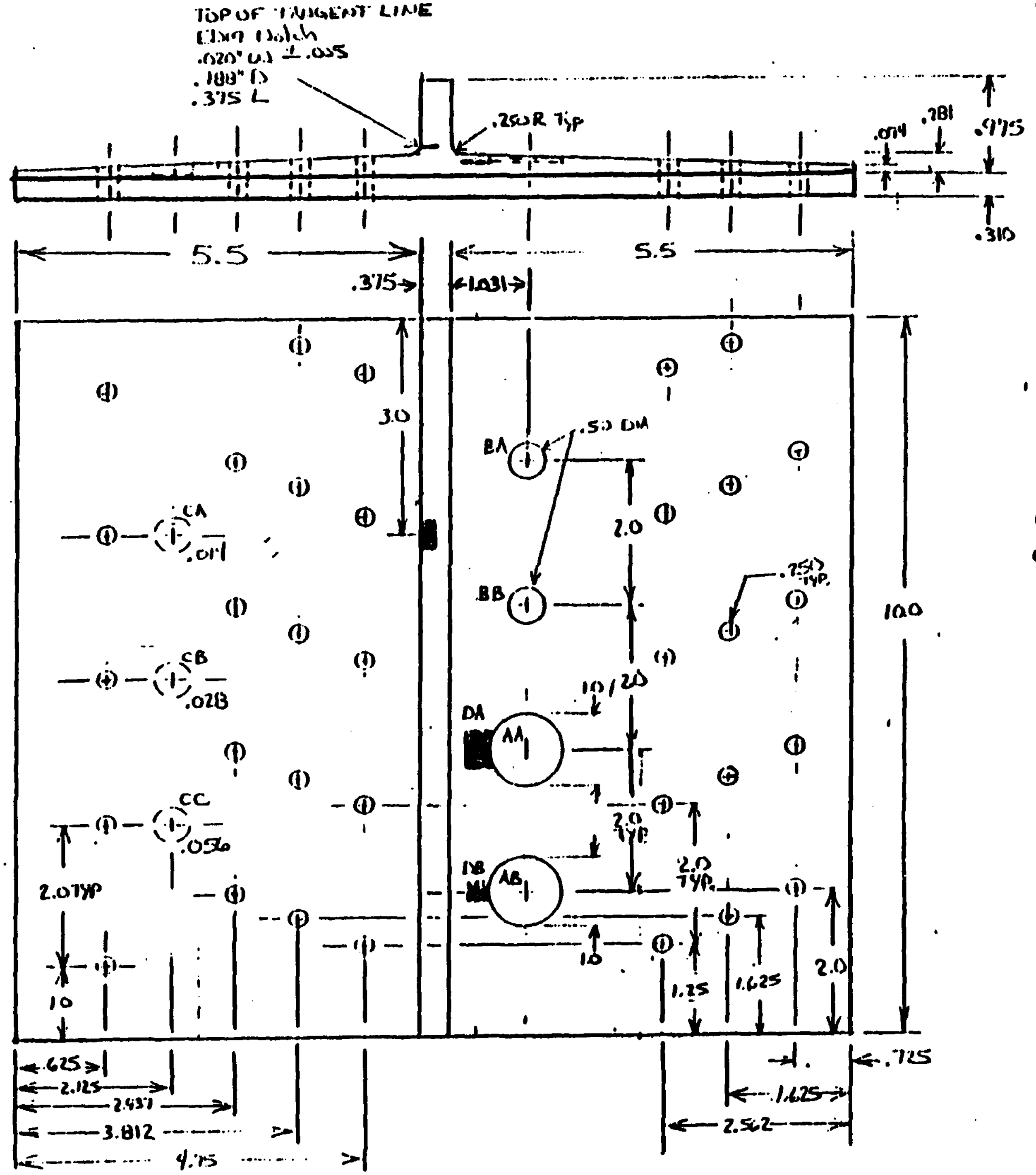
PLATE .310

MFG FROM 7075-T6

Tolerance

.XX .010

.XXX .005



SPOT FACE SCH

AA .056

AB .056

BA .028

BB .014

CA .014

CB .028

CC .056

EDM IN ROTRYMNT SPOT FACE

DA .020 W

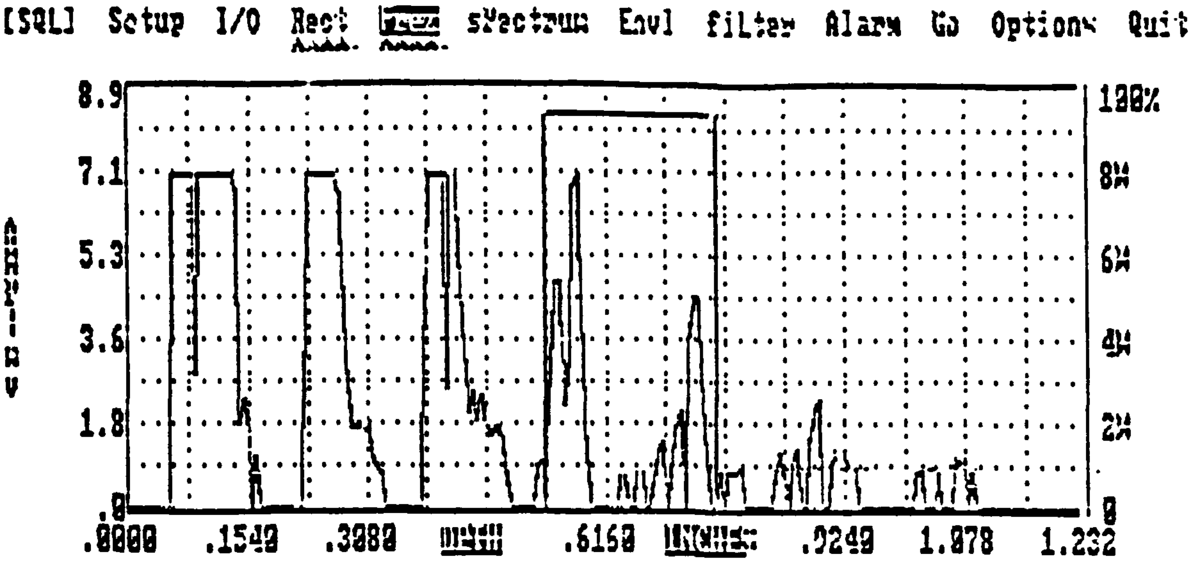
.100 D

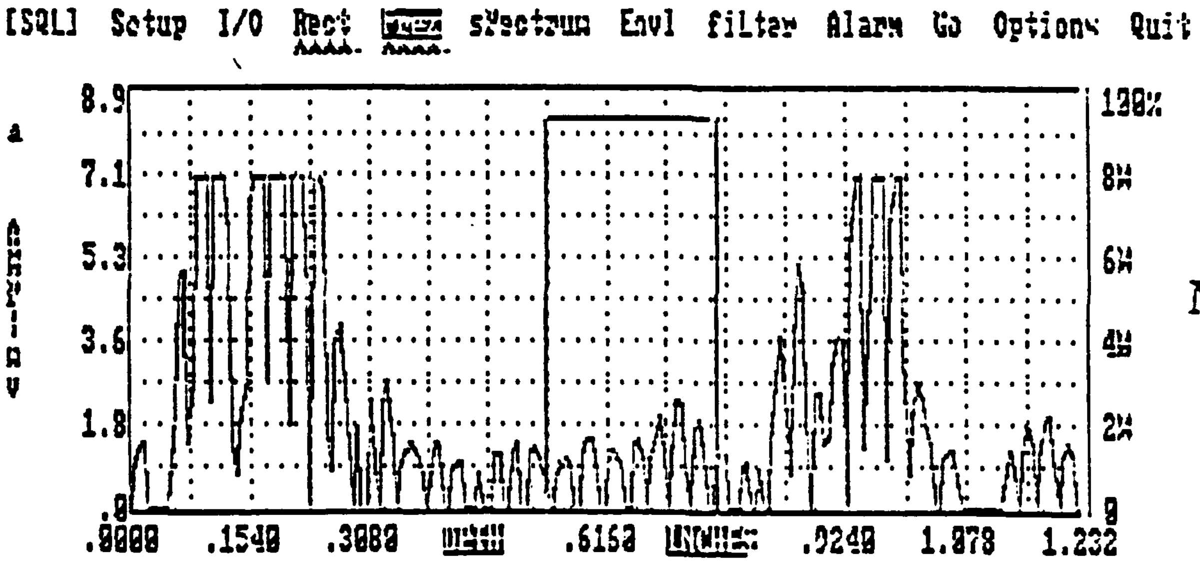
.375L

DB .020 W

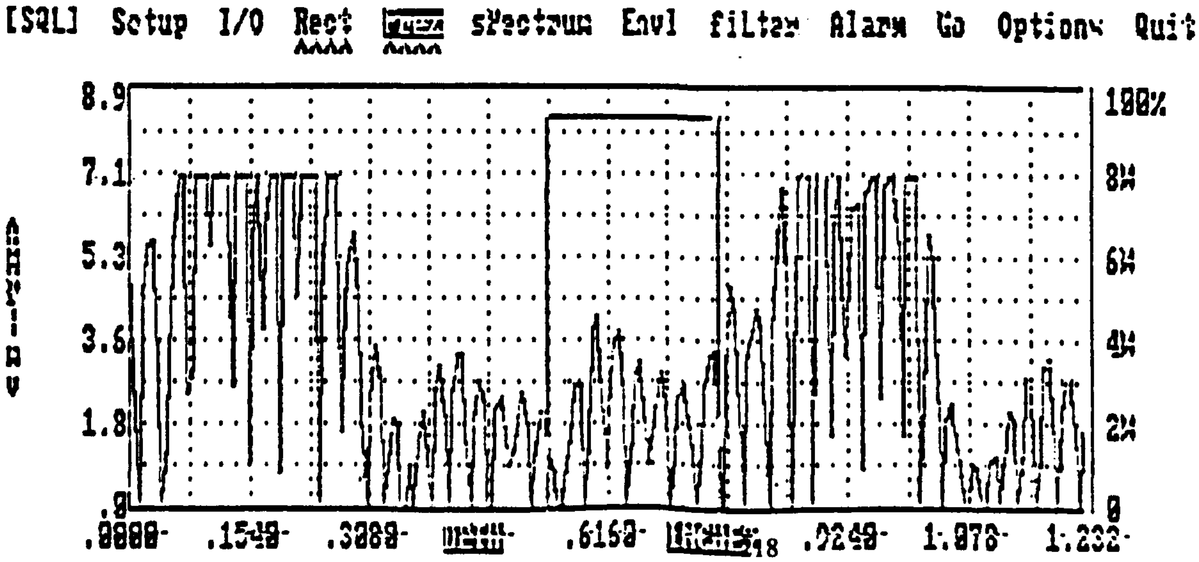
.100 D

.25 L



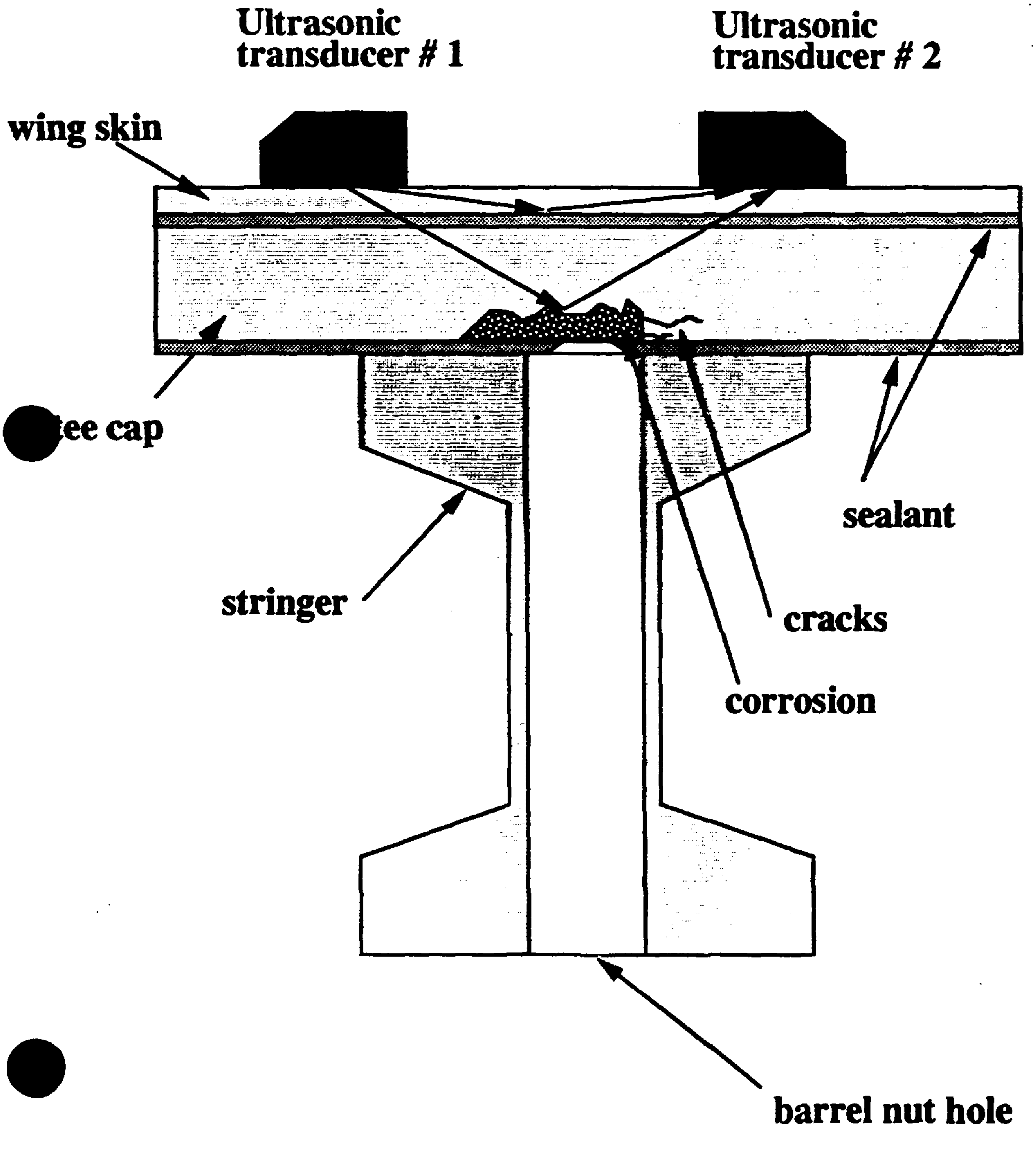


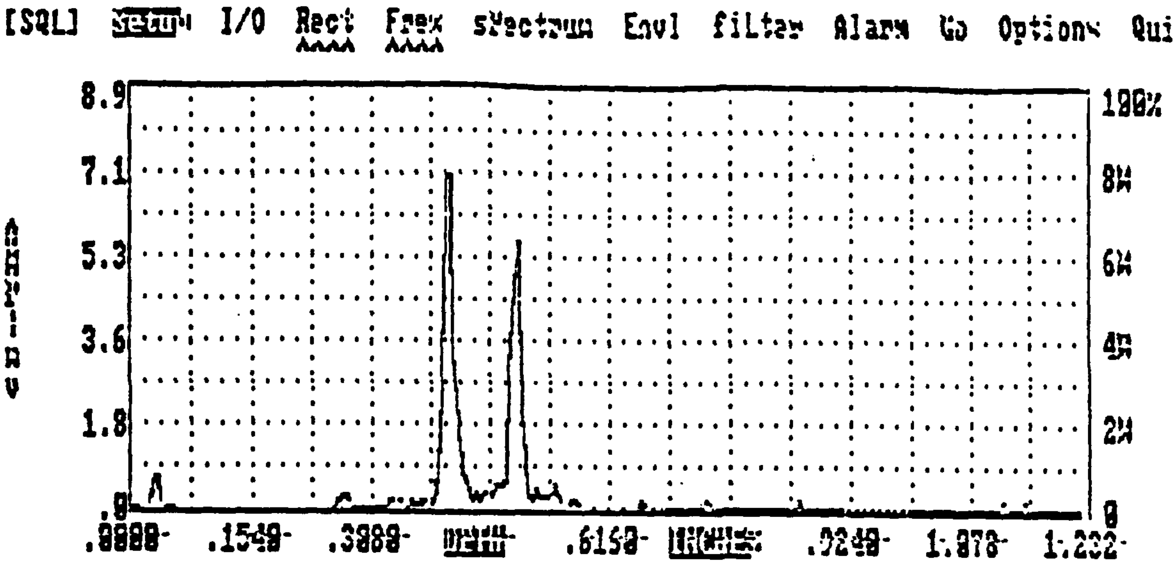
NO FLA

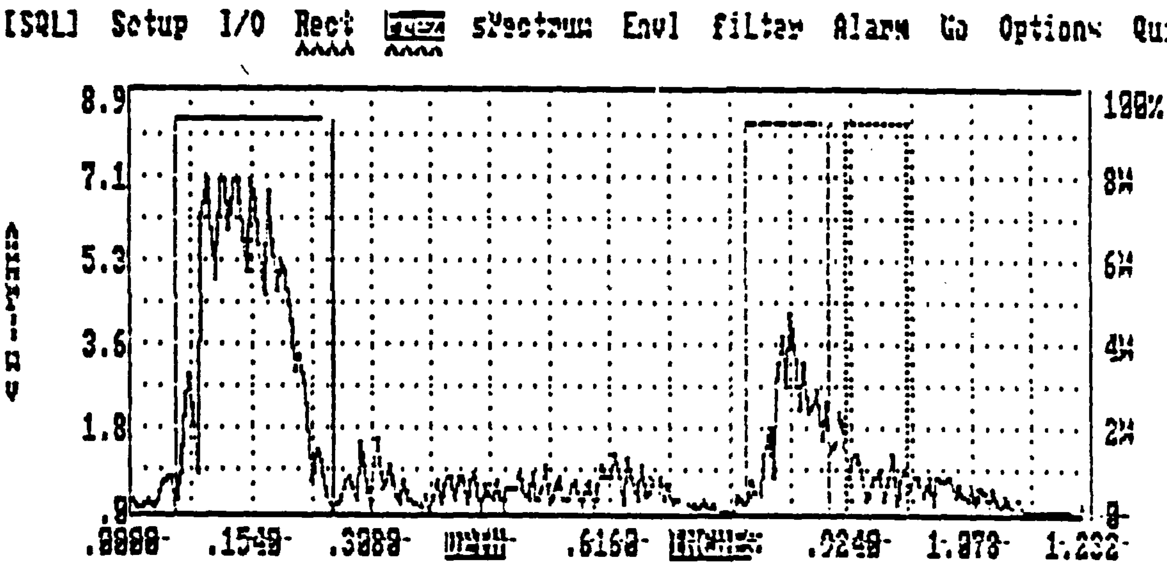


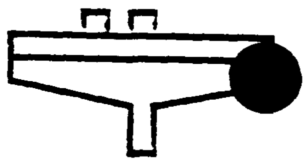
FLAW

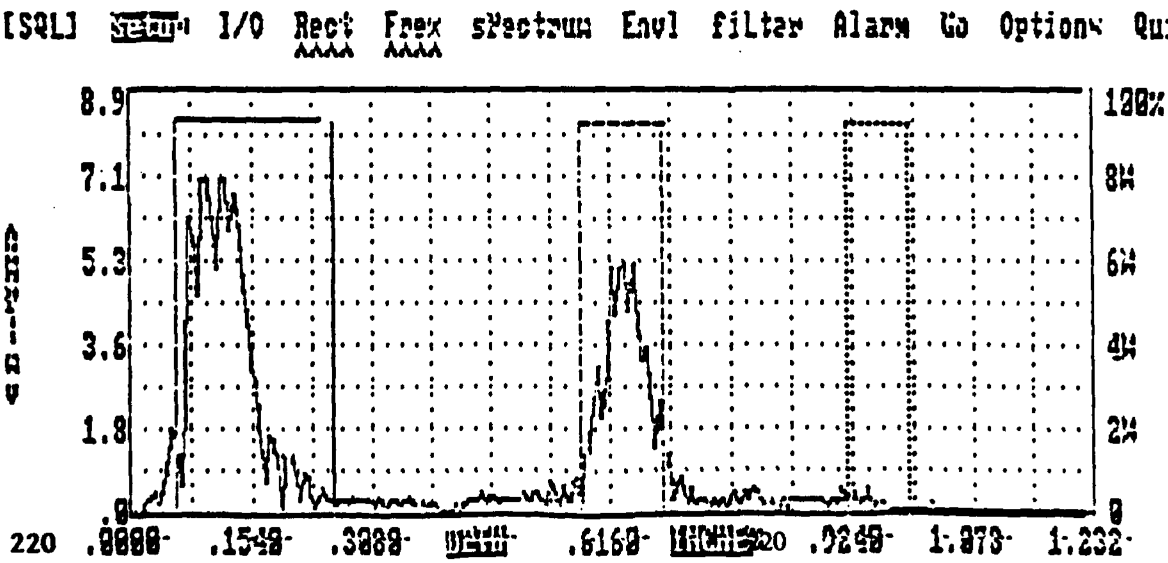
Ultrasonic inspection of DC-9 Wingbox




[SQL] Setup I/O Rect Frex sPectrum Envl filter Alarm Go Options Quit
8.9
7.1
5.3
3.6
1.8
0
100%
80%
60%
40%
20%
0
.0000 .1540 .3080 .6160 .9240 1.078 1.232


[SQL] Setup I/O Rect Frex sPectrum Envl filter Alarm Go Options Quit
8.9
7.1
5.3
3.6
1.8
0
100%
80%
60%
40%
20%
0
.0000 .1540 .3080 .6160 .9240 1.078 1.232




[SQL] Setup I/O Rect Frex sPectrum Envl filter Alarm Go Options Quit
8.9
7.1
5.3
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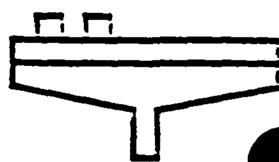
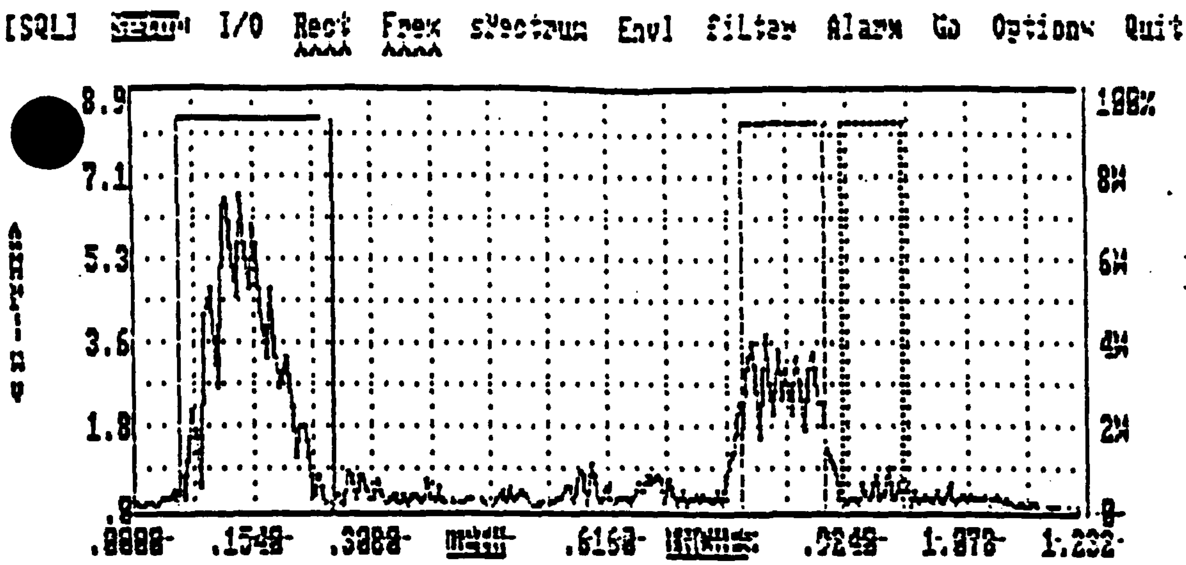
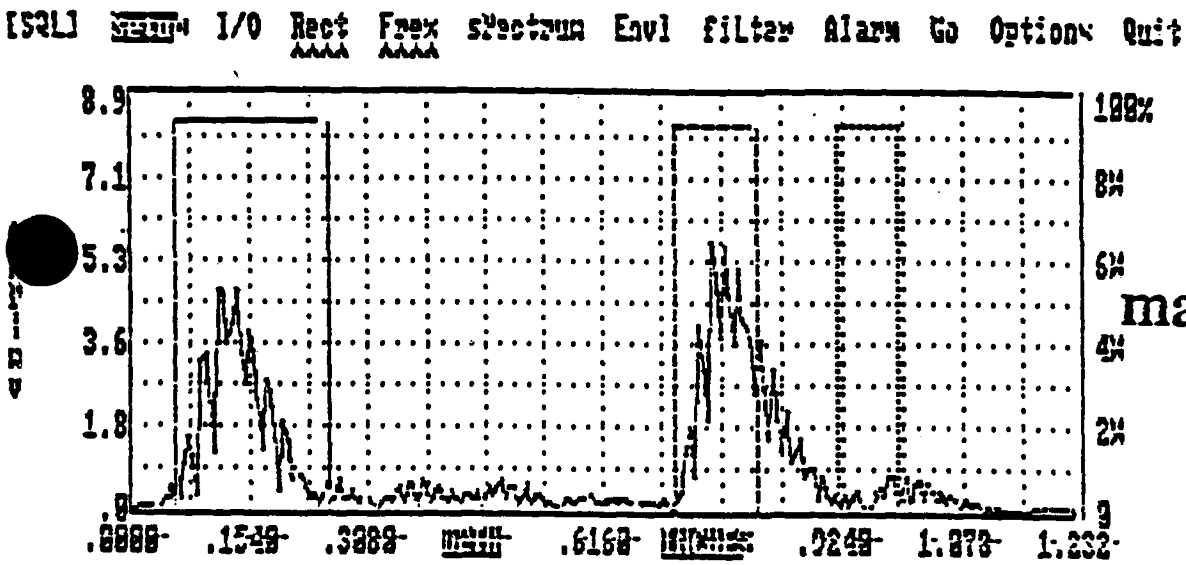
0
.0000 .1540 .3080 .6160 .9240 1.078 1.232

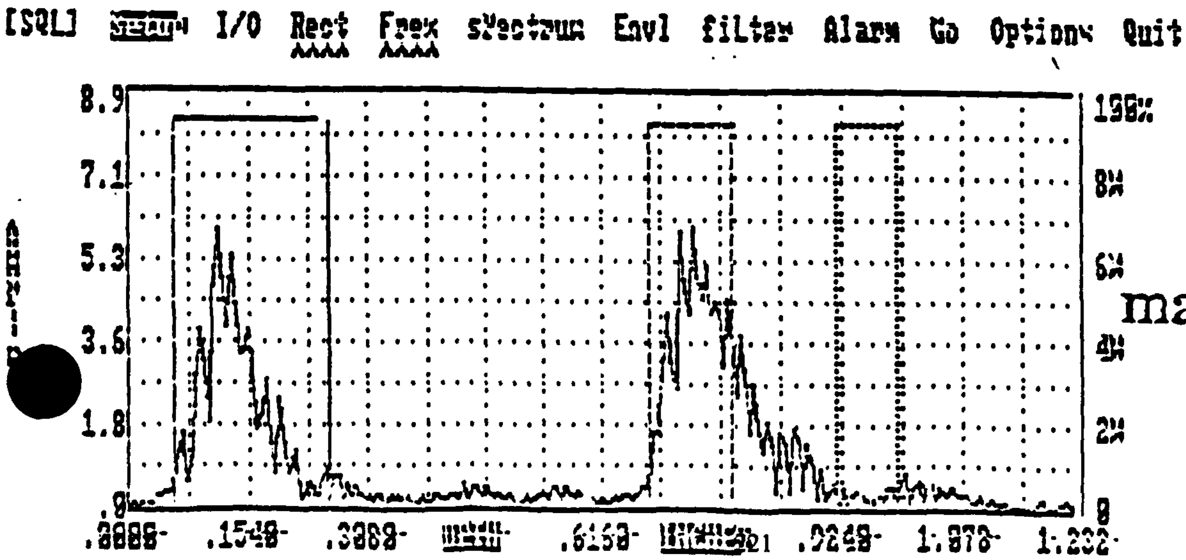




NO FLAW



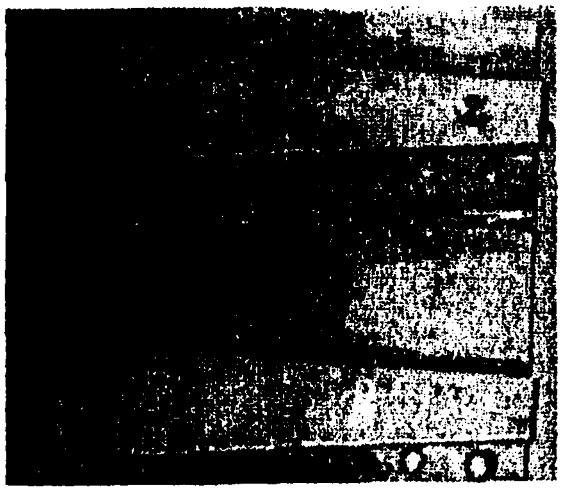
10%
material loss

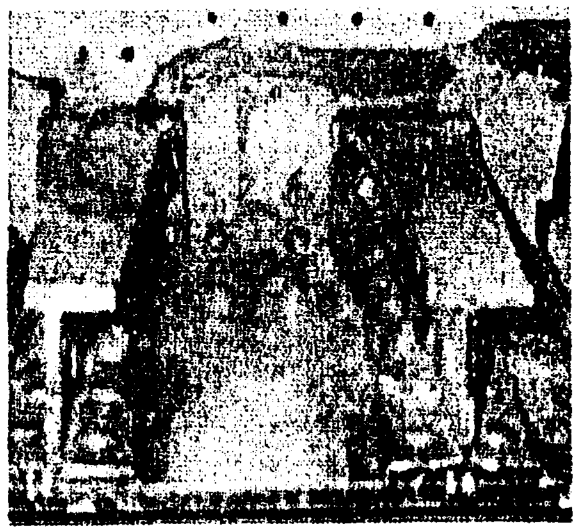


20%
material loss

Sample #2 is a cut-out section of the wing box from a DC-9.

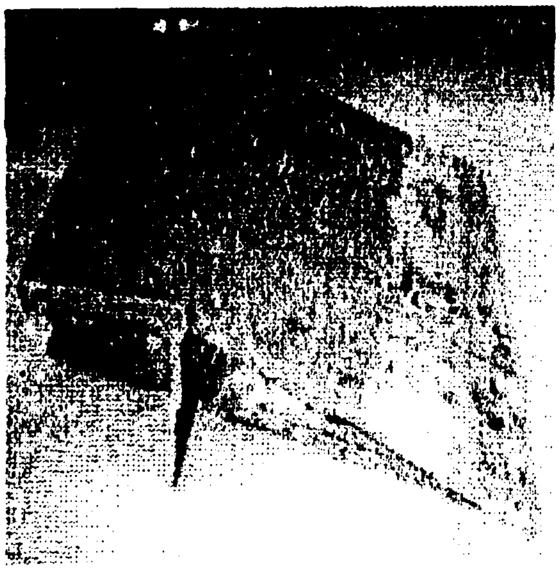
- Sample #2 from Northwest Airlines

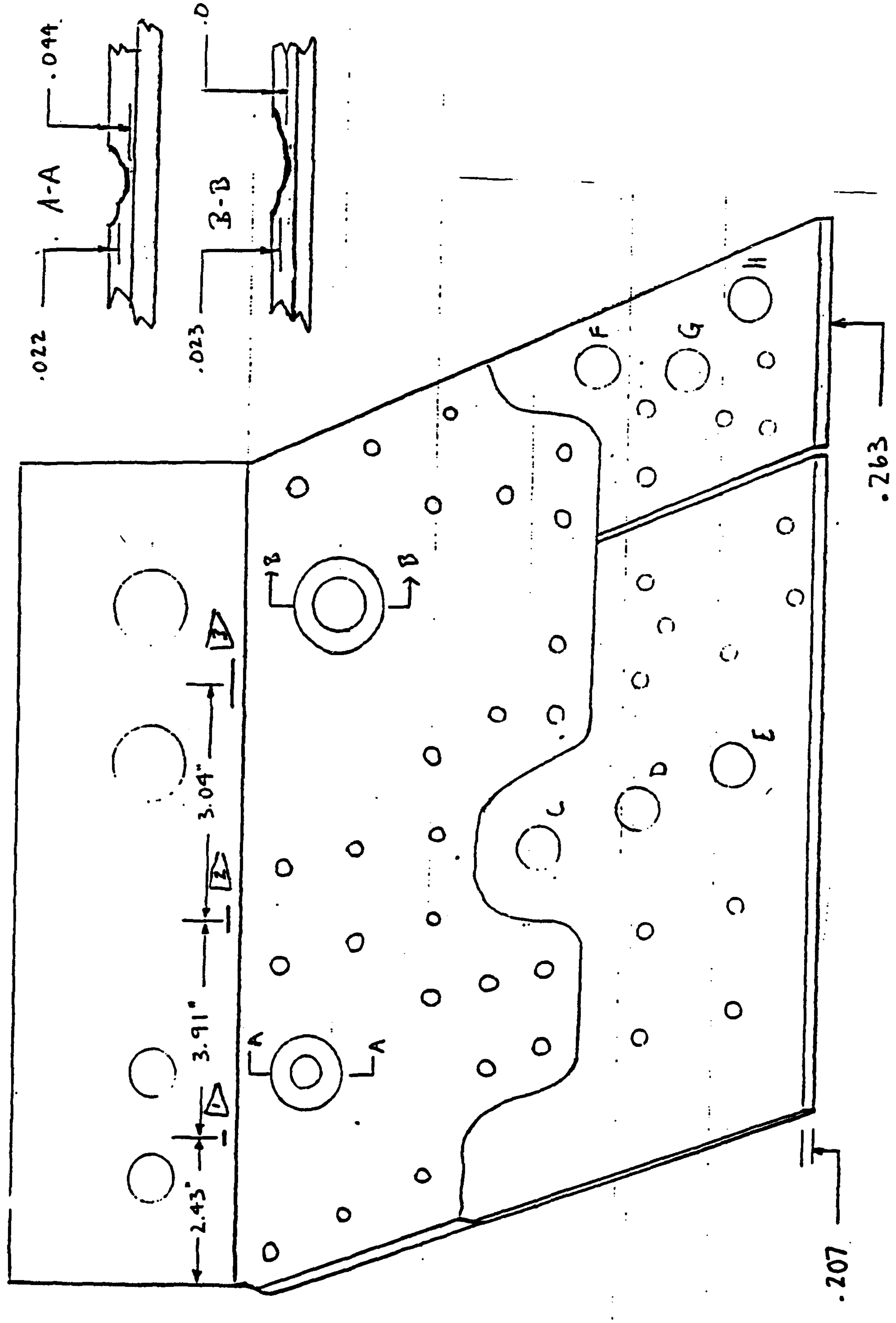




Sample #3 is part of a wing box from a DC-9 with embedded artifical corrosion defects at the Tee cap to stringer interface.

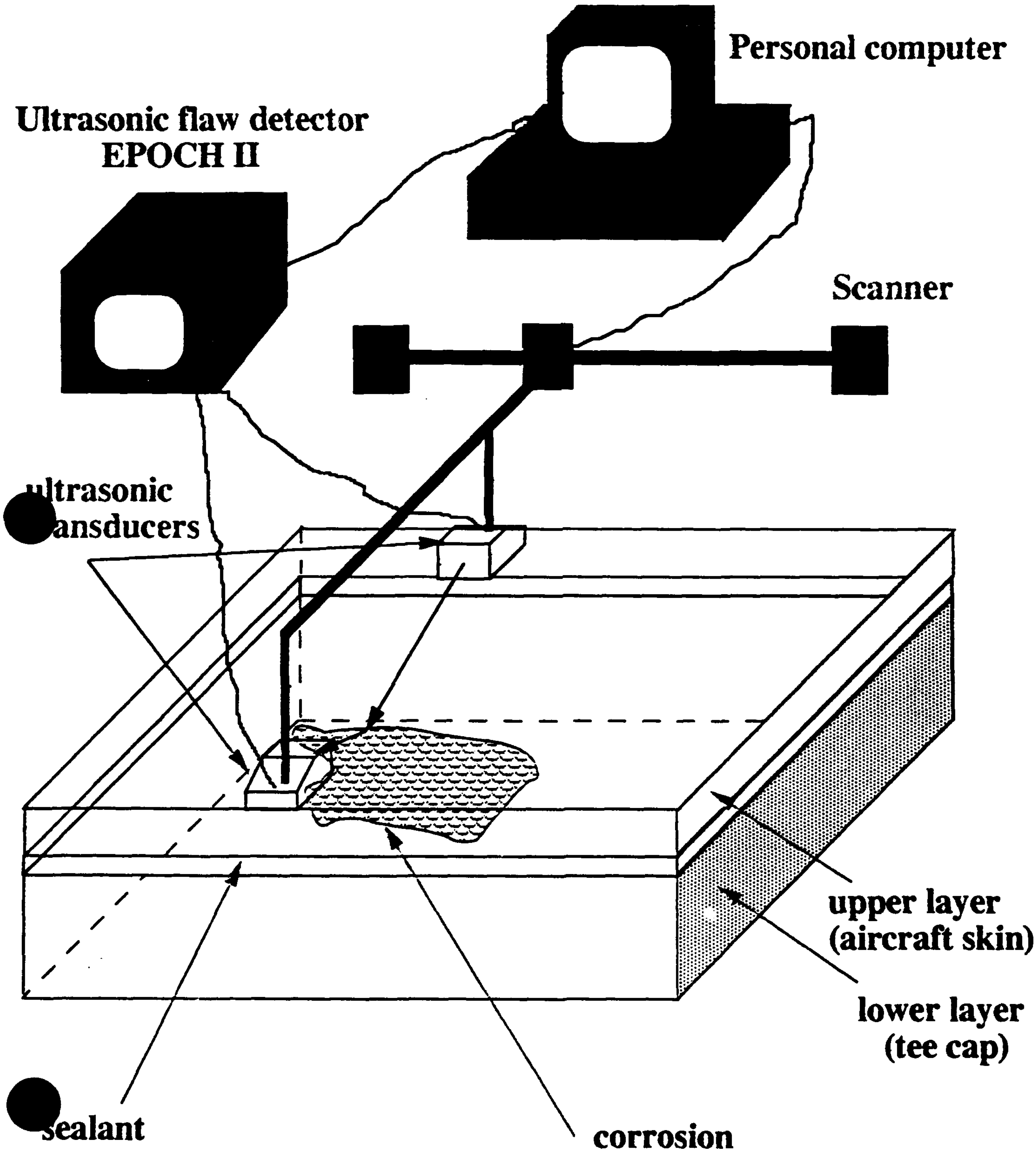
- Sample #3 from Northwest Airlines



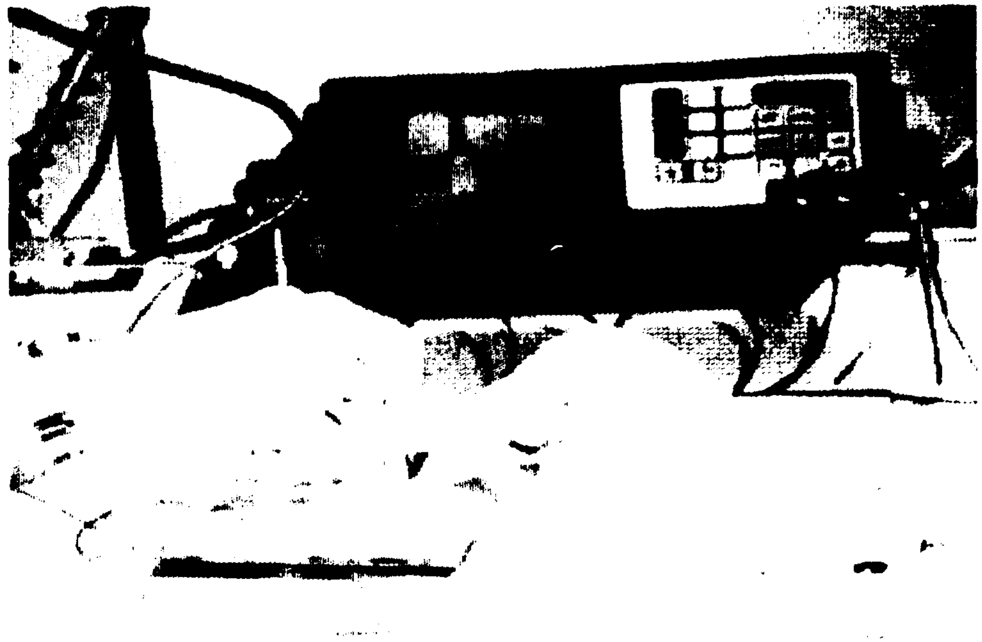


A-A
.022
.044
B-B
.023
.046
2.43"
3.91"
3.04"
A
B
C
D
E
F
G
H
.263
.207

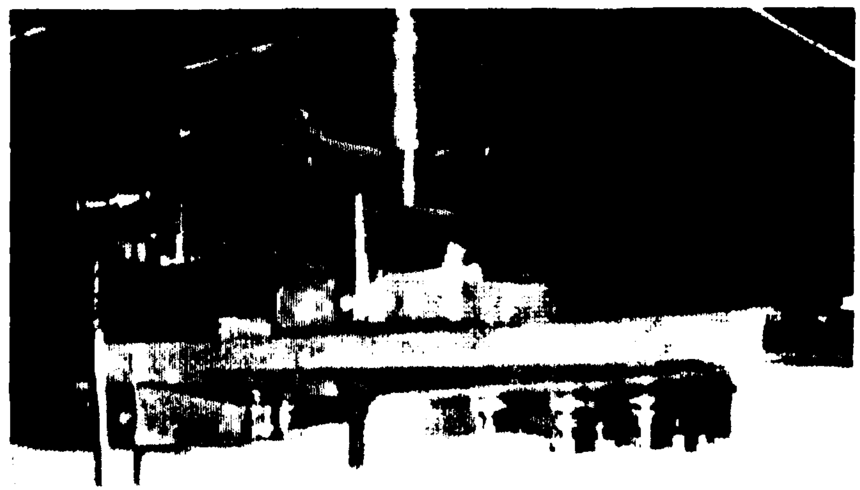
Experimental configuration for ultrasonic inspection of DC-9 Wingbox



Adjustment of transducer configuration for ultrasonic inspection on Sample #1.



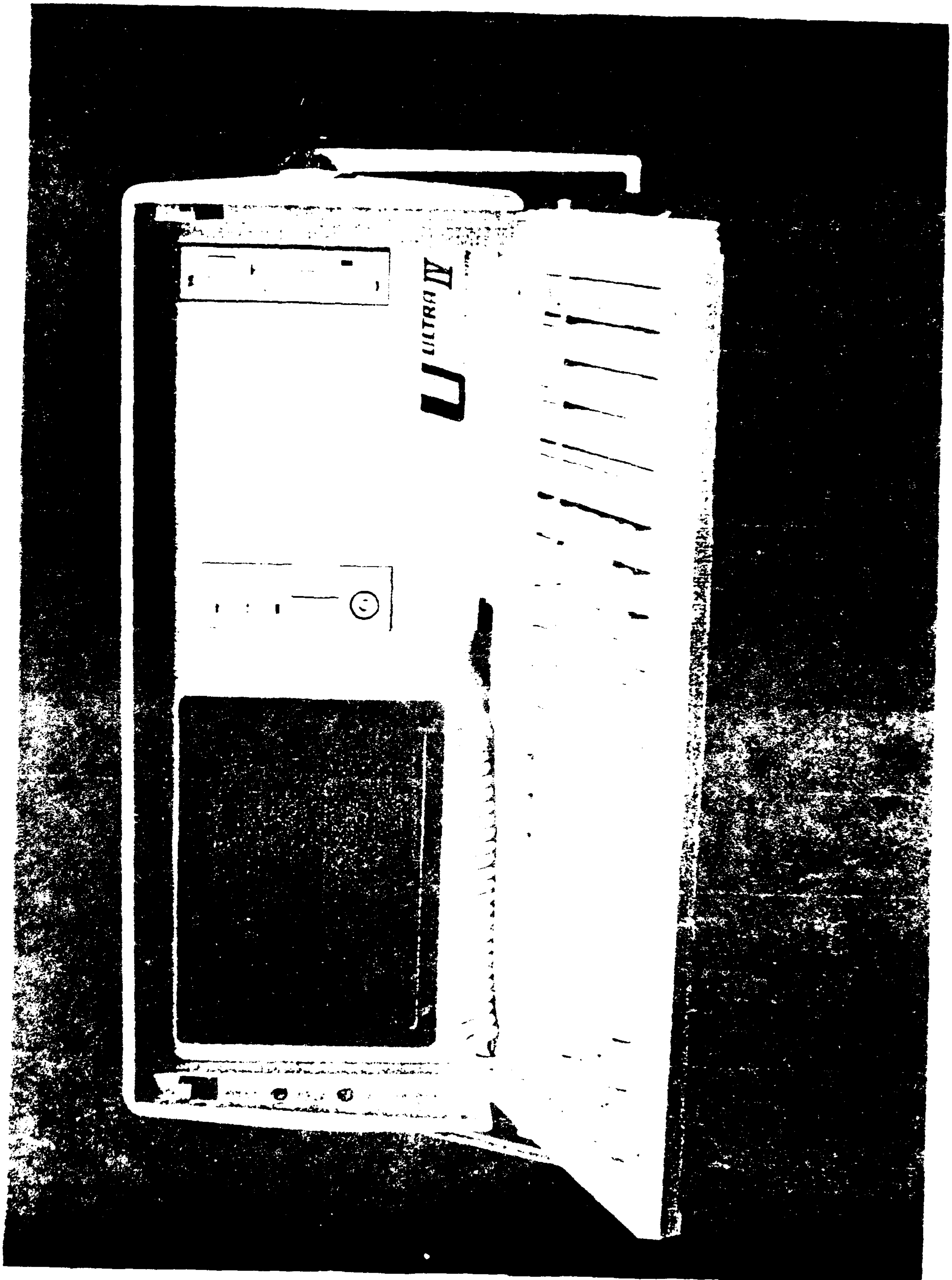
Mechanical scanning of Sample #1.

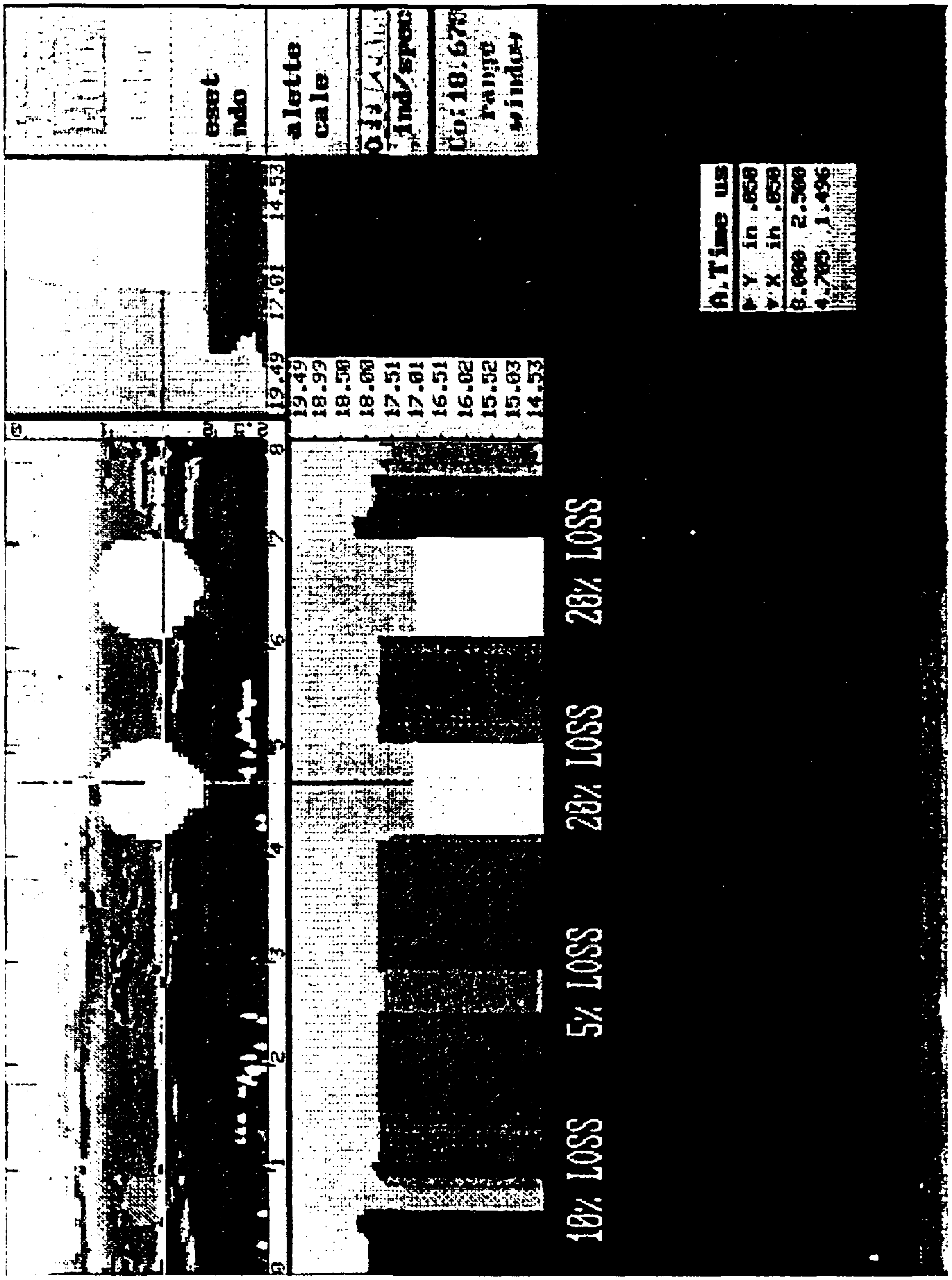


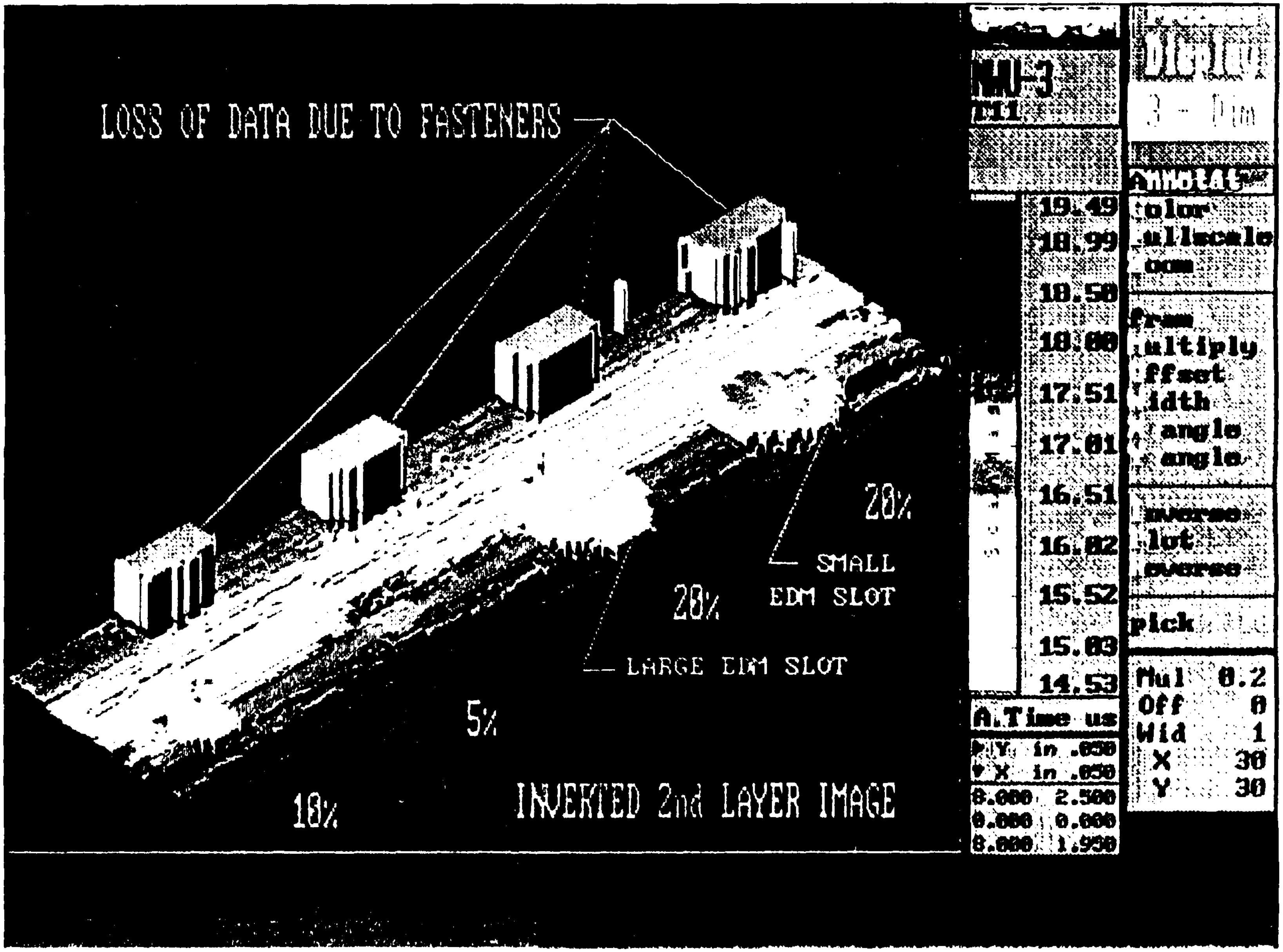
CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION

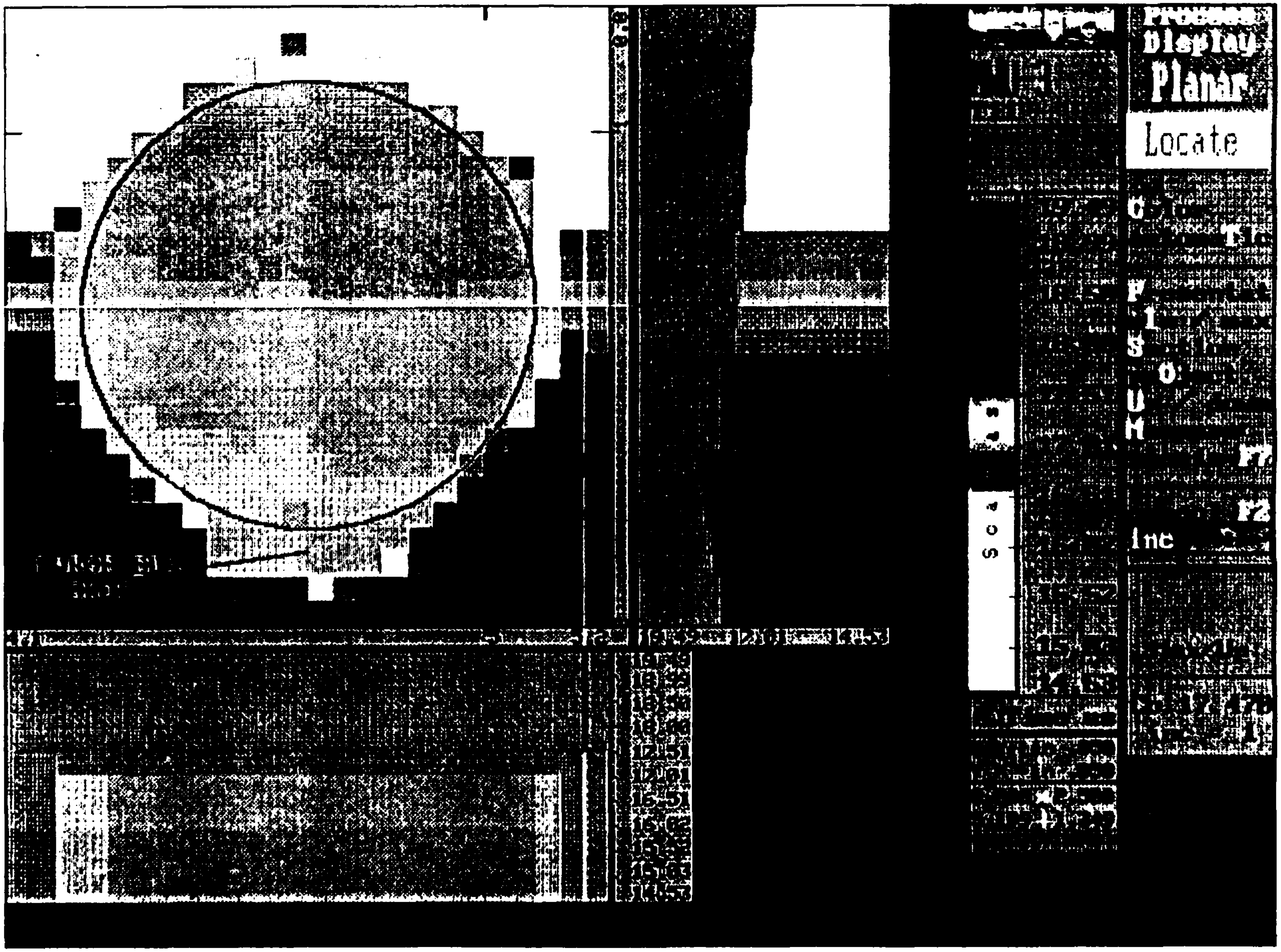
Integrated system for scanning, data acquisition and imaging.

CENTER FOR QUALITY ENGINEERING AND FAILURE PREVENTION

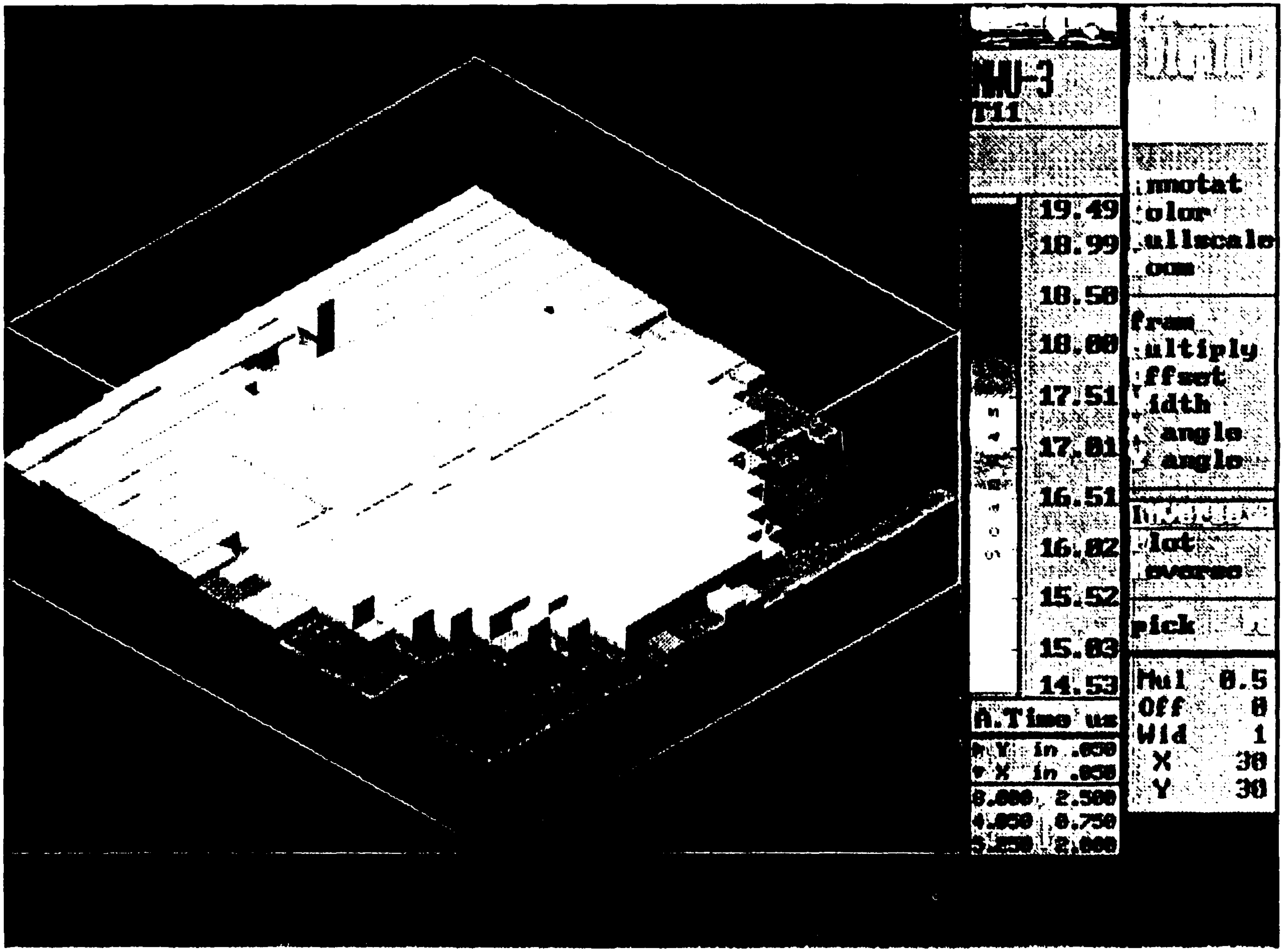

ULTRA IV


10% LOSS
5% LOSS
20% LOSS
20% LOSS
A.Time us

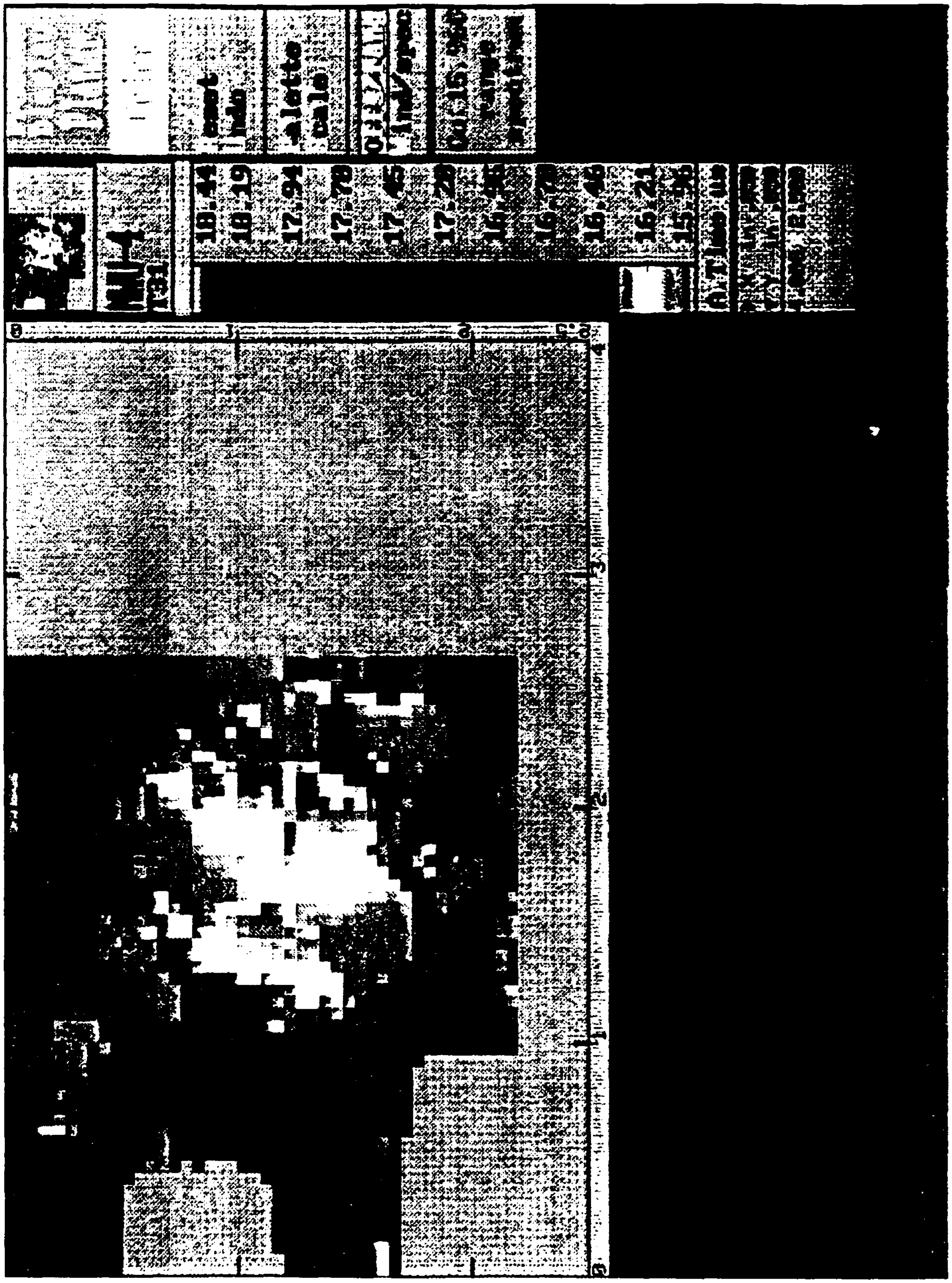

LOSS OF DATA DUE TO FASTENERS
20%
SMALL
EDM SLOT
20%
LARGE EDM SLOT
5%
10%
INVERTED 2nd LAYER IMAGE
Display
3 - Dim
19.49
18.99
18.50
18.00
17.51
17.01
16.51
16.02
15.52
15.03
14.53
A.Time us
Y in .050
X in .050
0.000 2.500
0.000 0.000
0.000 1.950
Mul 0.2
Off 0
Wid 1
X 30
Y 30
pick

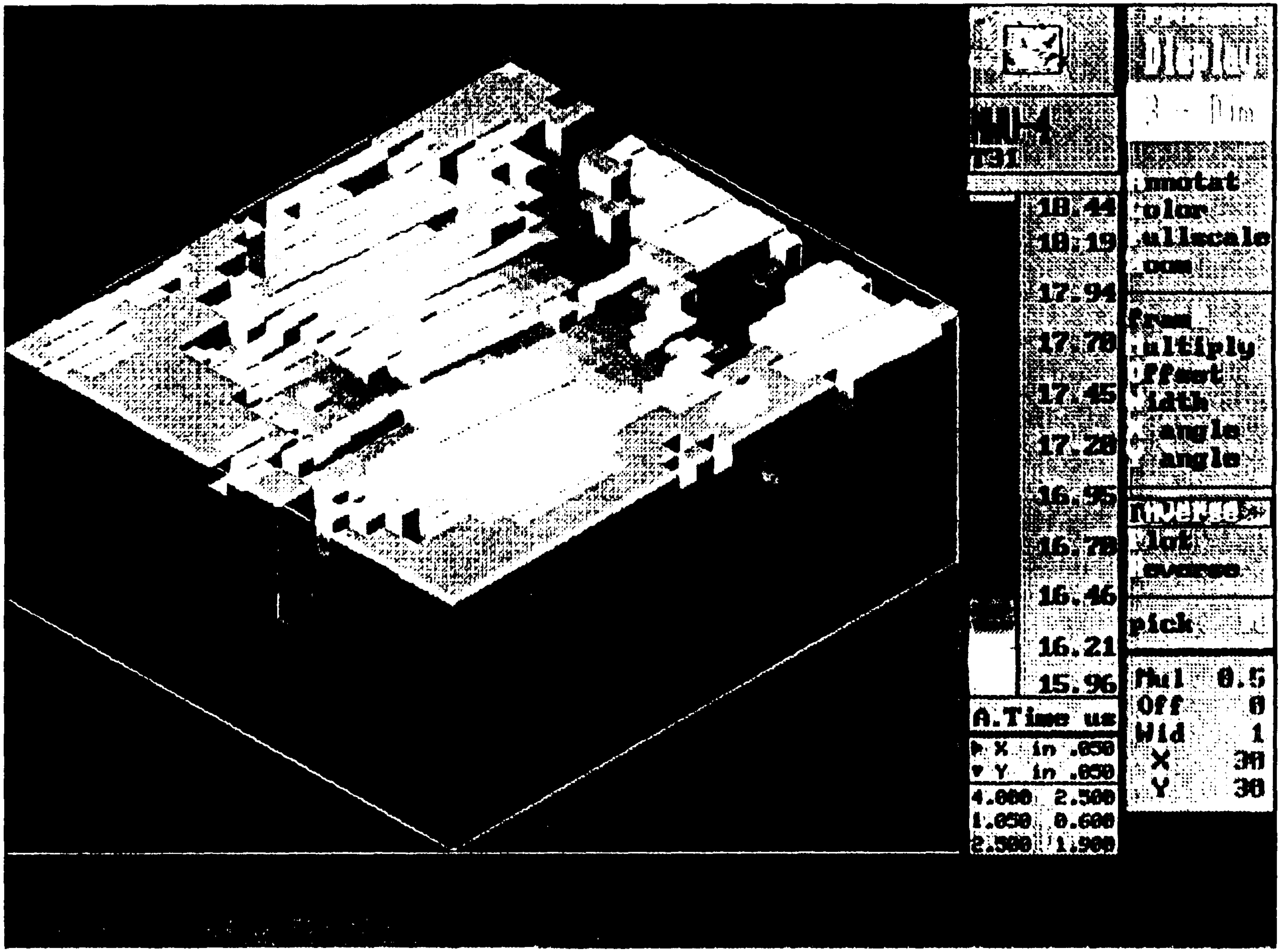


ZOOM of 1" SPOTFACE DETAILS EDM ~~NOTCH~~ SLOT



INVERTED 3-D IMAGE OF SURFACE WITH EDM SLOT.


18.44
18.19
17.94
17.70
17.45
17.20
16.95
16.70
16.46
16.21
15.96



3-D IMAGE OF SPOT FACE W/ CORROSION PRODUCTS-

FAA CASR

FAA Center for Aviation Systems Reliability

FAA-CASR Technology Transfer Plan

Dale Chimenti
Iowa State University

Robert Thomas
Wayne State University

Jan Achenbach
Northwestern University

FAA Center for Aviation Systems Reliability

FAA-CASR Technology Transfer Plan

- ➤Neural net wheel inspection beta site at NWA (ISU)
- ➤ESPI licensed to Laser Technology Inc (NWU)
- ➤Realtime x-ray image enhancement beta site at NWA, DL (ISU)

- Self-compensating probe for DC-9 tee-cap (NWU)
- Dripless bubbler for lap-splice inspections (ISU)
- Self-compensating probe for DC-10 vert stablzr (NWU)
- Thermal wave imaging system devlopment (WSU)
- X-ray backscatter depth profilometer, AANC demo (NWU)
- Advanced, wide dynamic range x-ray film densitometer (ISU)
- X-ray simulator multiple beta site and AANC demo (ISU)
- Precision eddy current calibrator multiple beta site and POD study (ISU)

FAAREV ISU 4-94

Dripless Bubbler Overview

FAA Center for Aviation Systems Reliability

NEED

- Airline survey shows interest in reliable, rapid, large-area U/S scan capability (UA, AA, NW, DL, USA)
  - Disbonds
  - Corrosion
  - Repair/thinning discrimination
  - Over protruding, buttonhead rivets, lap-splice edges
  - Compatible with hangar maintenance environment

RESPONSE

- Unique, captured-water volume U/S probe and detection method
  - Rapid scan capability
  - Reliable, consistent water coupling
  - Scans over protruding rivets
  - No uncontained water
  - Interchangeable, focused transducers
  - Immersion techniques implementable on A-C structure

FAAREV ISU 4-94

Dripless Bubbler Technical Approach

GOALS FOR TECHNOLOGY

- Lap splices
  - Disbonds
  - Corrosion

- Detection sensitivity, and resolution
  - 1/2" x 1/2" disbond
  - 10% metal thinning in top layer over 1/4" x 1/4"

- Scan capability
  - Scan over protruding rivets
  - Maintain consistent U/S coupling
  - Reproducibility of images
  - Scan rate of 1/2 foot of 4-inch lap splice per hour over button-head rivets

FAAREV ISU 4-94

Dripless Bubbler Approach II

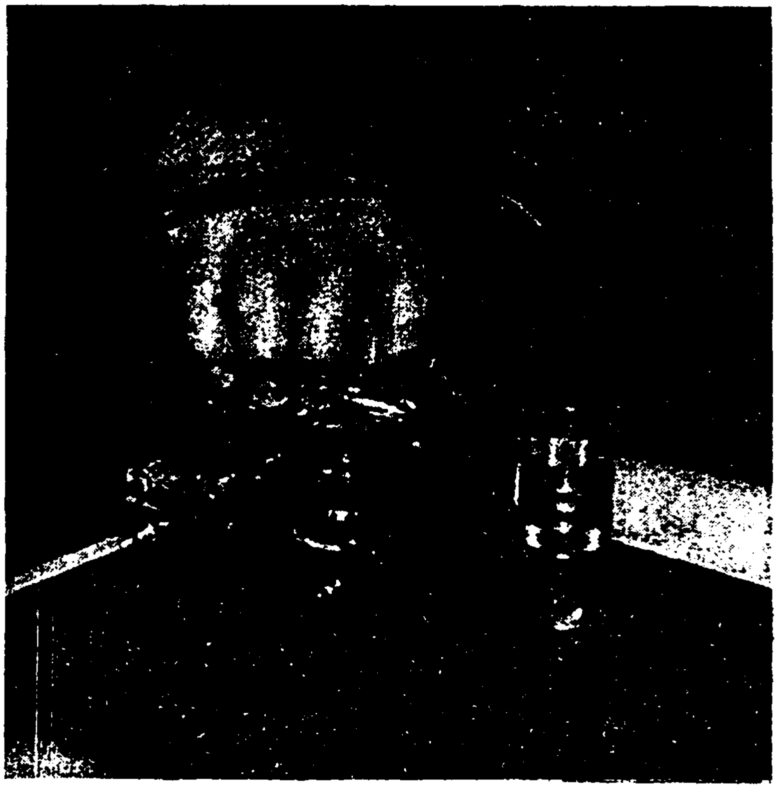
FAA Center for Aviation Systems Reliability

PLAN

- Engineer bubbler head to reduce size, weight
- Optimize water delivery and recovery system
- Develop quick connect/disconnect system for rapid transucer interchange
- Improve wear resistance and water containment capabilities of bubbler head
- Fusion of dripless bubbler with existing scanner technology
  - strong interest from McDonnell-Douglas

FAAREV ISU 4-94

Dripless Bubbler Combined with MAUS III



MAUS III sweeps out a band at a time, can follow gradual contour, scans long sections of lap splice continuously, and has multi-mode capability.

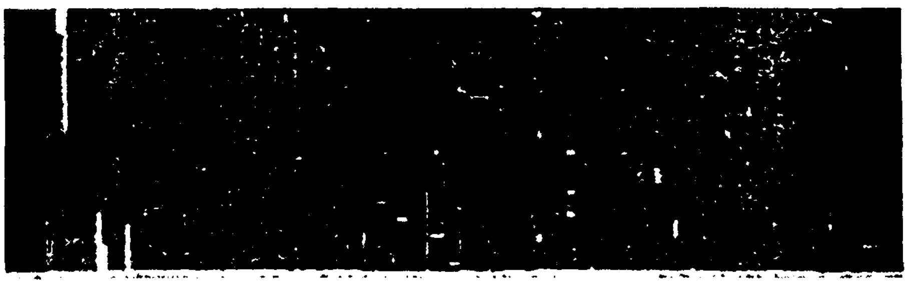


Image of corrosion in Boeing #6 sample as obtained by dripless bubbler and MAUS III with 15 MHz, 2" focus transducer. Scan area = 6.5" x 2"

DB+ MAUS III.pg

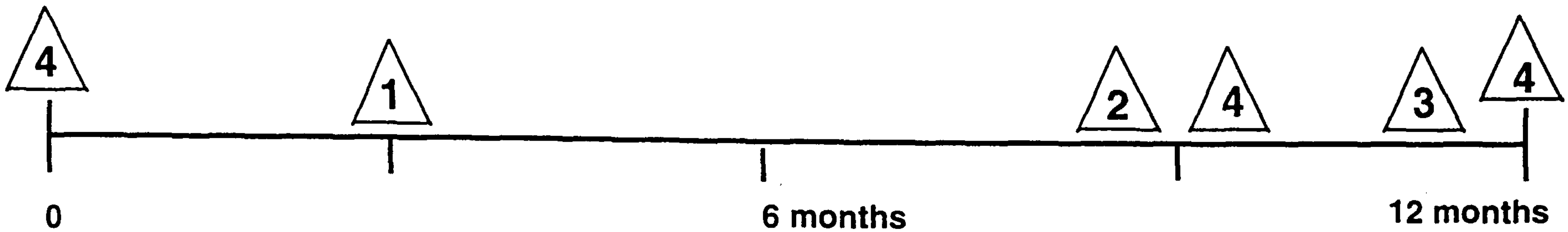
General Evaluation Comments

- Portability
  - Compact package is easy to transport and assemble
  - All inspection modes in one package is a unique feature
- Setup Ease
  - Initial setup is very fast and straightforward
  - Simple operator menus are easily understood
- Versatility
  - Various inspection methods allow evaluation of many structures
  - Scanner designs enable inspections in any orientation
  - Data Measurement capabilities are quite useful
- Flexibility
  - Configuration changes accomplished in less then five minutes
  - Easy configuration makes system adaptable for many inspections

MCDONNELL DOUGLAS AEROSPACE

Dripless Bubbler Schedule

FAA Center for Aviation Systems Reliability



1. Reduce size, weight; develop coupling
   - engineer probe head to available transducers

2. Optimize water coupling, foam rings
   - max rivet height, diameter
   - floor ops. or maint. stand, physical dims. of A/C structure
   - Vacuum capabilities, pump capabilities

3. Fusion with scanner

4. On-site testing at AANC

FAAREV ISU 4-94

X-ray Film Densitometer Overview

NEED

- Improve sensitivity in radiographs
- Eliminate the need for multiple film loading
- Recover information from high density regions
- Low-cost instrument

RESPONSE

- Low-cost film densitometer, off-the-shelf components
- Innovative CASR-developed software to acquire images
- Expanded dynamic range using image segmentation
    - increased sensitivity
    - broadened density range

X-ray Film Densitometer Overview

FAA Center for Aviation Systems Reliability

GOALS FOR TECHNOLOGY

- Improve flaw detection sensitivity
- Reduce film costs
    - elimination of multiple loading
- Contrast sensitivity to 0.5 to 1% contrast sensitivity levels
    - factor of 2 to 4 improvement

FAAREV ISU 4-94

PLAN

- Adapt light box to computer control
- Extend XRVISION graphical user interface for film density data acquisition
- Integrate 16-bit image screen viewer with 16-bit data acquisition software
- Develop calibration procedure for light box and camera

X-ray Film Densitometer Overview

FAA Center for Aviation Systems Reliability

1. Demo initial capability on lab system using industrially supplied radiographs
2. Complete PC control of light box
3. Extend XRVISION GUI to file data acquisition
4. Incorporate 16-bit frame integration
   16-bit frame viewer
5. Beta test at Northwest Airlines, coordinate with AANC
6. Complete calibration procedures for light box and camera
7. On-site test at AANC

FAAREV ISU 4-94

Simulator Overview

FAA Center for Aviation Systems Reliability

NEED

A cost-effective means for evaluating optimal inspection capabilities and limits for x-ray radiography

- Make tactical trade-offs among cost, sensitivity, and spatial resolution
- Evaluate adequacy of inspections for which no established procedure exists
    - repairs
    - commuters
    - unanticipated failuare modes beyond design life
- Douglas has requested license
- Interest from Boeing
- Interest from Northwest and Delta

FAAREV ISU 4-94

RESPONSE

A workstation-based, Windows-driven rapid x-ray inspection simulator:

XRSIM

- 37 parameters are realistically modeled including:
  - x-ray generator characteristics
  - beam size
  - beam filtration
  - complex shapes from CAD drawings
  - response from various film types
  - set-up configurations

GOALS FOR TECHNOLOGY

- Collect user feedback on:
  - useability
  - performance
  - convenience
  - features

- Provide user training and ongoing customer support (1-800-HOTLINE)

Simulator Overview

FAA Center for Aviation Systems Reliability

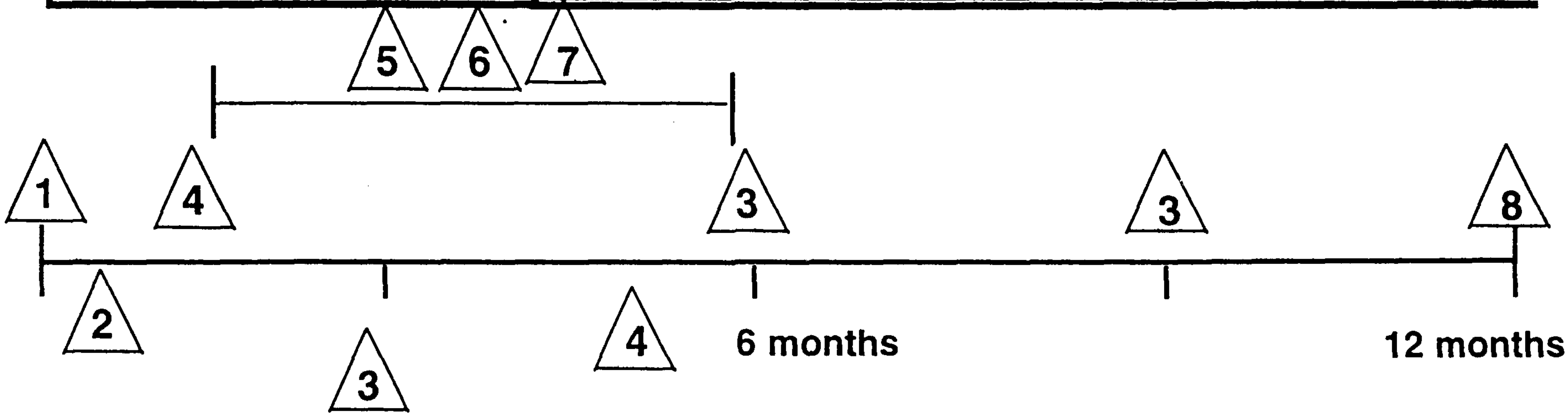
PLAN

- Port XRSIM to low-cost UNIX workstation
- Beta test workstations at several sites (3-4 months each)
- Expand x-ray generator and film data base
- Extend CAD model data base to include additional geometries (by customer request)

FAAREV ISU 4-94

Simulator Overview

FAA Center for Aviation Systems Reliability



1. X-ray sim demo at AANC
2. Develop evaluation form
3. Beta site test at AANC, OEM, and airlines
4. Port XRSIM to lost-cost workstation
5. Addition to x-ray generator data base
6. Addition of film type to XRSIM
7. Addition of CAD object models
8. Summarize and report on evaluations

FAAREV ISU 4-94

EC Probe Calibrator Overview

NEED

Experience and extensive testing of probes from a variety of sources shows need for objective, quantitative method for characterizing eddy current probe quality and standardizing probes used for aircraft inspection. Individual probes can vary by as much as 300-400% in response to flaws, affecting quality and uniformity of testing.

RESPONSE

New probe characterization method based on laser-based mapping of eddy current probe's electromagnetic field

- Quantitative and objective
- Predicts probe response to flaws
- Improve probe design and manufacturing
- Specification and incoming inspection of new probes

GOALS FOR TECHNOLOGY

- Reduce overall cost for producing instrument to < 10 k$
- Improve sensitivity to low frequency probes (500 Hz and up)
- Re-engineer operating software to improve ease of use
- Function with absolute, differential, and reflection probes
- Spatial resolution of 0.2 mm (8 mils)

EC Probe Calibrator Approach II

FAA Center for Aviation Systems Reliability

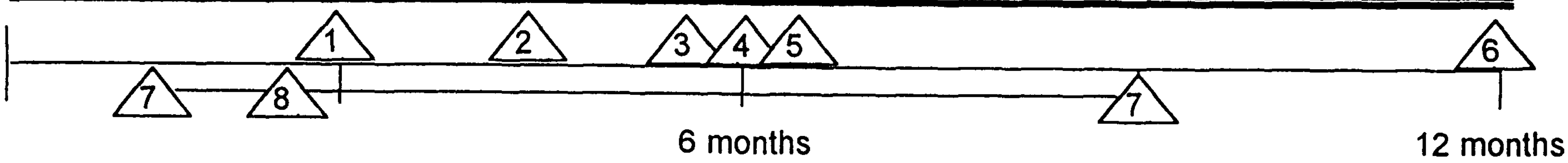
PLAN

- Engineer new prototype to reduce system cost to <10 k$
- Improve operation for low frequency probes
  - Thicker witness plate
- Improve user interface with new software, user manuals
  - MS Windows based
- Manufacture additional prototype instruments
- Prepare training program for beta testers
- Arrange for beta-site testing with probe manufacturer, OEM, and airline
  - Preliminary contacts with NDT Engr. and Zetec show strong interest
  - Boeing agreed to participate in validation study

FAAREV ISU 4-94

EC Probe Calibrator Schedule

FAA Center for Aviation Systems Reliability



- △1 Engineer new prototype, reducing cost to <10 k$
- △2 Improve operation for low frequency probes
- △3 Improve user interface with new operating software, user manual
- △4 Complete manufacturing of additional instruments
- △5 Training for beta-site testers
- △6 Complete beta testing
- △7 Correlation of EC Calibrator results with POD study at AANC
- △8 Comparison with Boeing probe tester

FAAREV ISU 4-94

FAA CASR

FAA Center for Aviation Systems Reliability

PROGRAM OVERVIEW

DALE CHIMENTI
FAA-CASR
IOWA STATE UNIVERSITY

Tech Trans portion w/ Dale –

FAA
Center for Aviation Systems Reliability

FAA-CASR

Iowa State University
Northwestern University
Wayne State University
Tuskegee University

Engineering Research Development and Application

Education and Training

Engine Titanium Consortium

FAA-CASR

FAA
Center for Aviation Systems Reliability

Defining Characteristics of FAA-CASR R&D

- Problem focussed, 2-3 year efforts targeted for implementation
- NDE techniques developed as quantitative measurement tools.
- Laboratory tests and techniques pre-validated by comparison with theory and mini-demos.
- Data presentation schemes selected for compatibility with automated instrumentation.
- Technology transfer schemes pre-planned.

FAA-CASR

Clobject.ppt

FAA
Center for Aviation Systems Reliability

Objectives

- To develop quantitative nondestructive evaluation methods for aircraft structures and materials including prototype instrumentation, software, techniques and procedures

- To develop and maintain comprehensive education and training programs specific to the inspection of aviation structures including both theory and practice components

FAA CASR

FAA Center for Aviation Systems Reliability

CASR INDUSTRIAL INTERACTIONS

XRSIM, X-ray POD	FAA Tech Center, Boeing, Douglas, GE, NWA
Realtime X-ray Enh	DL, NWA, Northstar Imaging
Thermal Waves	AANC, NWA, Tinker AFB (ARINC), Lockheed-Georgia, Saudi Air
Neural Nets	UAL, NWA, Garrett, BF Goodrich, ABS, Candec
Dripless Bubbler	NWA, McDonnell-Douglas, Boeing, USAir, AANC(4/20-21)
Self-Comp Probe	Douglas, NWA, UAL

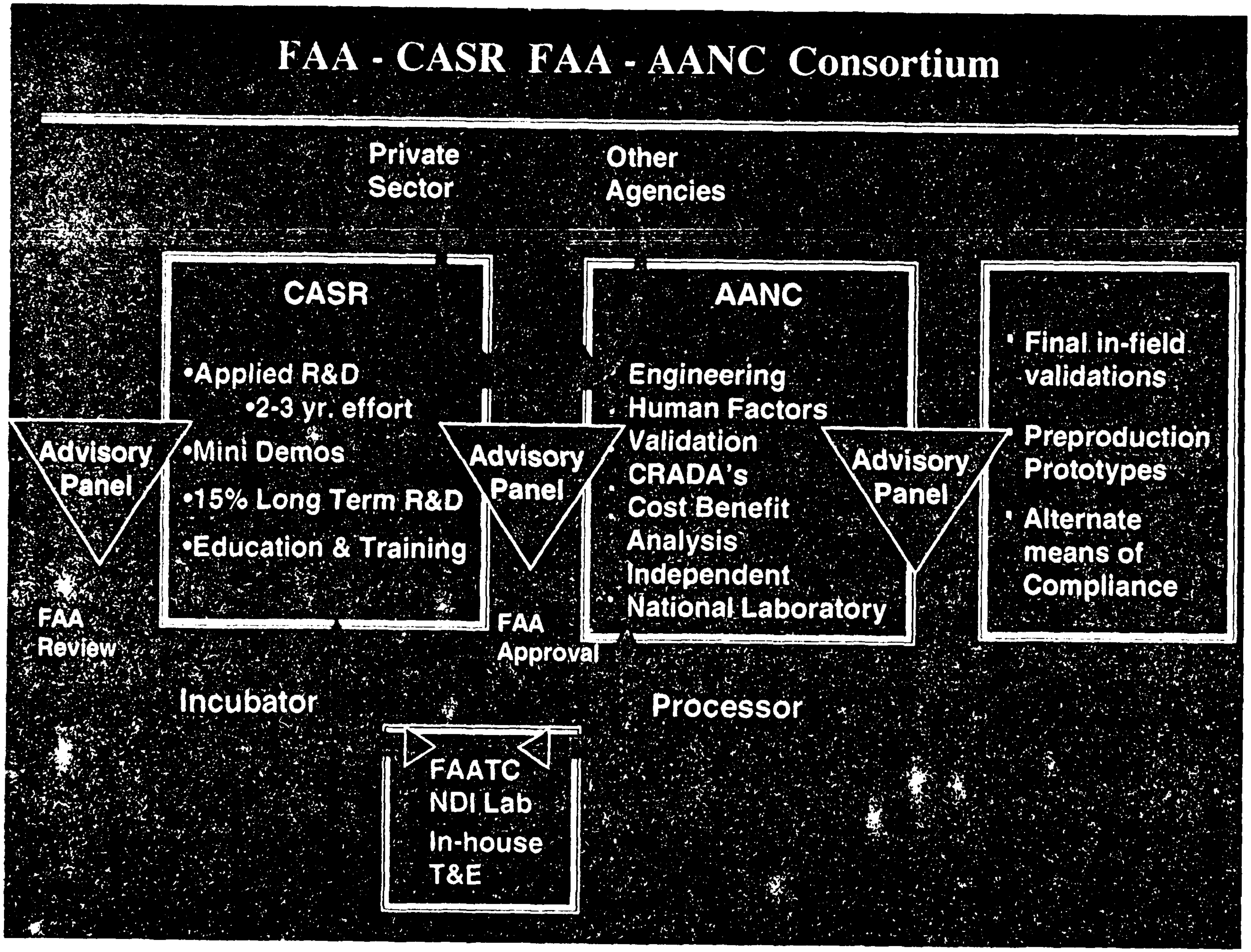
FAAREV ISU 4-94

FAA CASR

FAA Center for Aviation Systems Reliability

CASR INDUSTRIAL INTERACTIONS (con't.)

EC Corrsn Detection	Boeing, Douglas, CAF
EC Calib. Corp,	Boeing, NWA, UAL, GE, NDT Engineering
	Zetec
X-ray BDP	UAL, DL, AANC
Training	UAL, AA, NWA, NWAirlink, USAir, TWA, DL, FAA-TA, EPRI, FAA Regional Offices
ESPI	Laser Technology Inc (LTI)

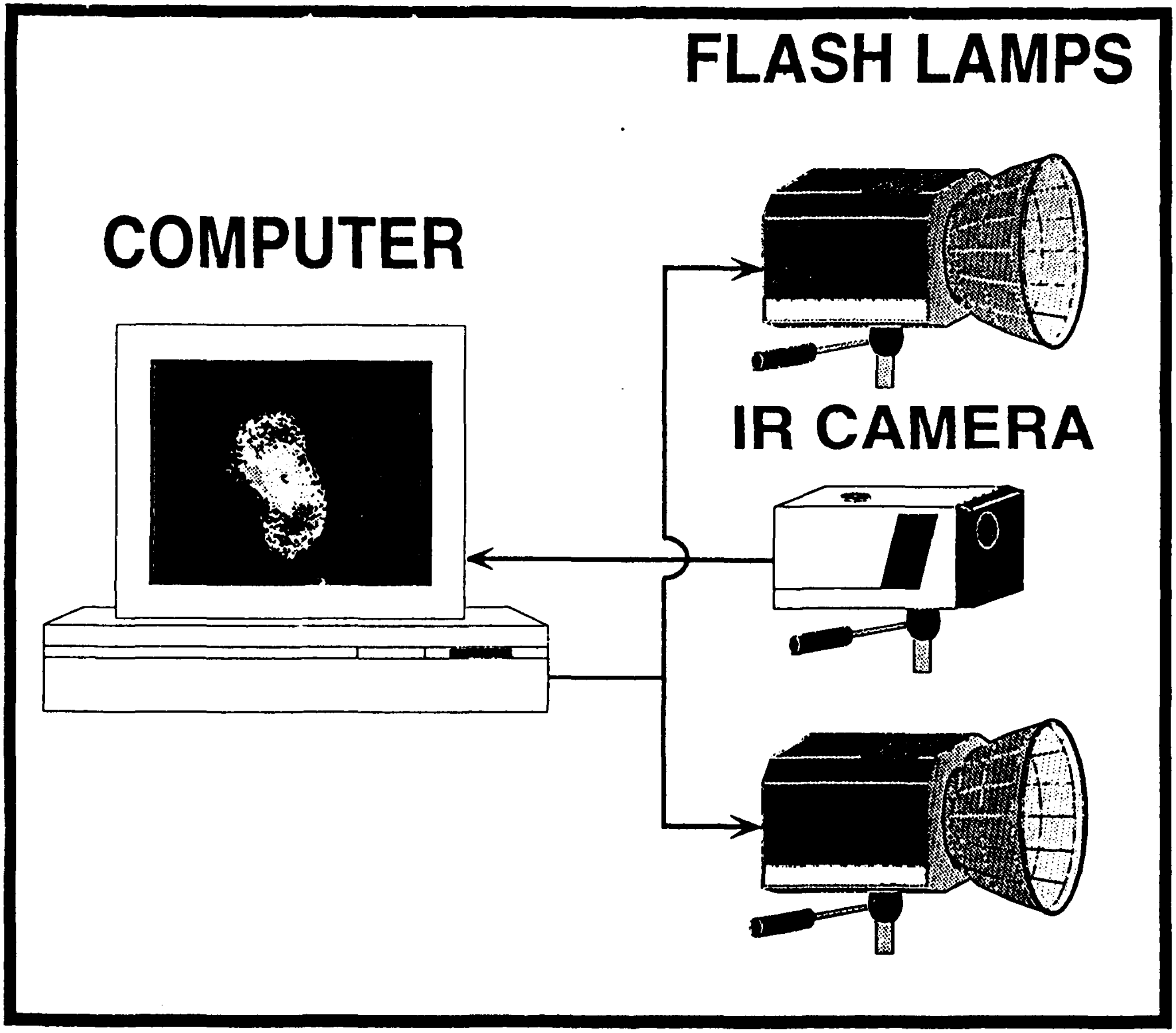

FAA - CASR FAA - AANC Consortium
Private Sector
Other Agencies
CASR
•Applied R&D
•2-3 yr. effort
•Mini Demos
•15% Long Term R&D
•Education & Training
AANC
Engineering
Human Factors
Validation
CRADA's
Cost Benefit Analysis
Independent
National Laboratory
Final in-field validations
Preproduction Prototypes
Alternate means of Compliance
Advisory Panel
Advisory Panel
Advisory Panel
FAA Review
FAA Approval
Incubator
Processor
FAATC
NDI Lab
In-house
T&E

TECHNIQUES FOR FLAW DETECTION
RPI 199

Tech Area: Adhesively Bonded and Composite Structure

Thermal Waves Imaging of Adhesive Bonds

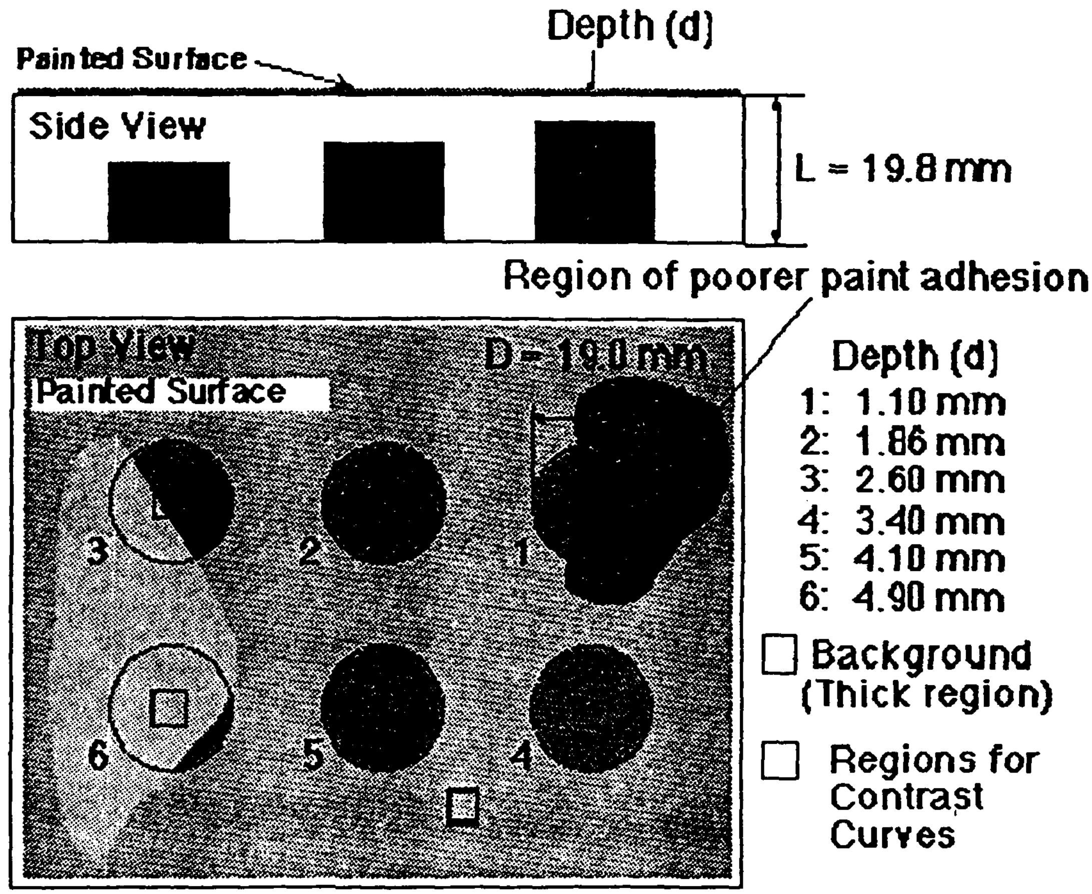
Dr. Robert L. Thomas
Wayne State University



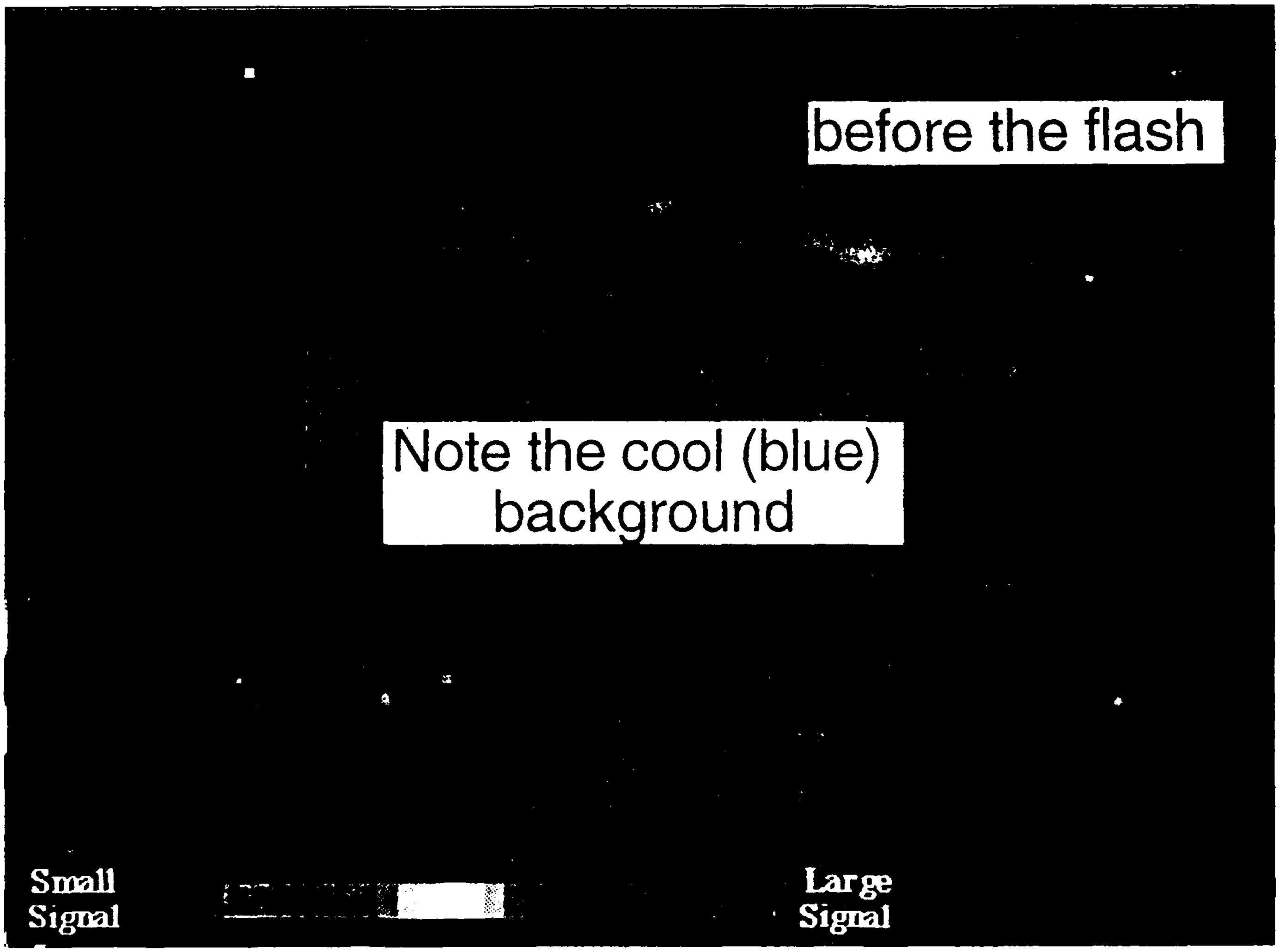
Schematic diagram of pulse-echo thermal wave imaging system.

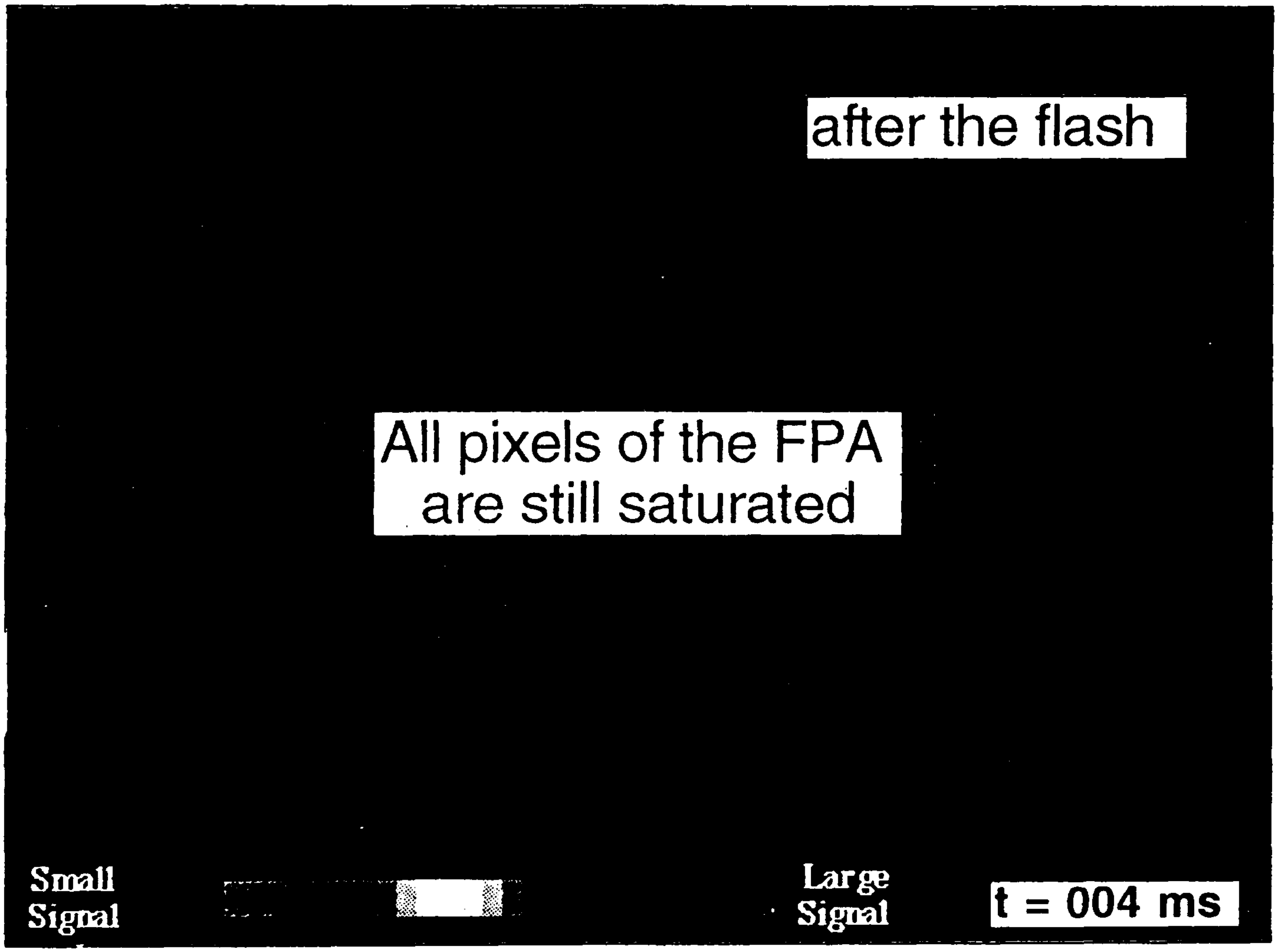
WAYNE STATE UNIVERSITY Institute for Manufacturing Research IMR

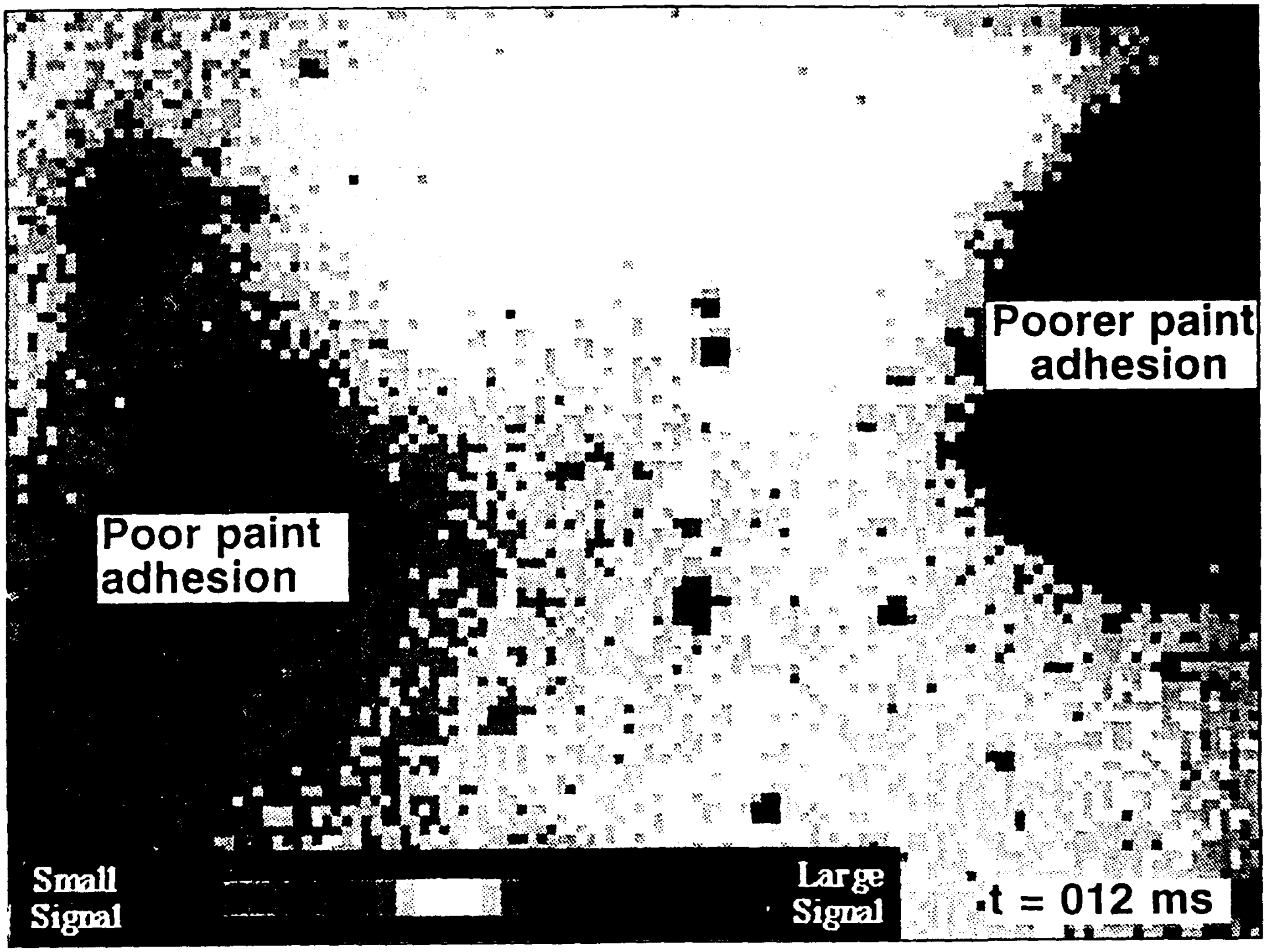
Corrosion.Fig.1.11.30.93

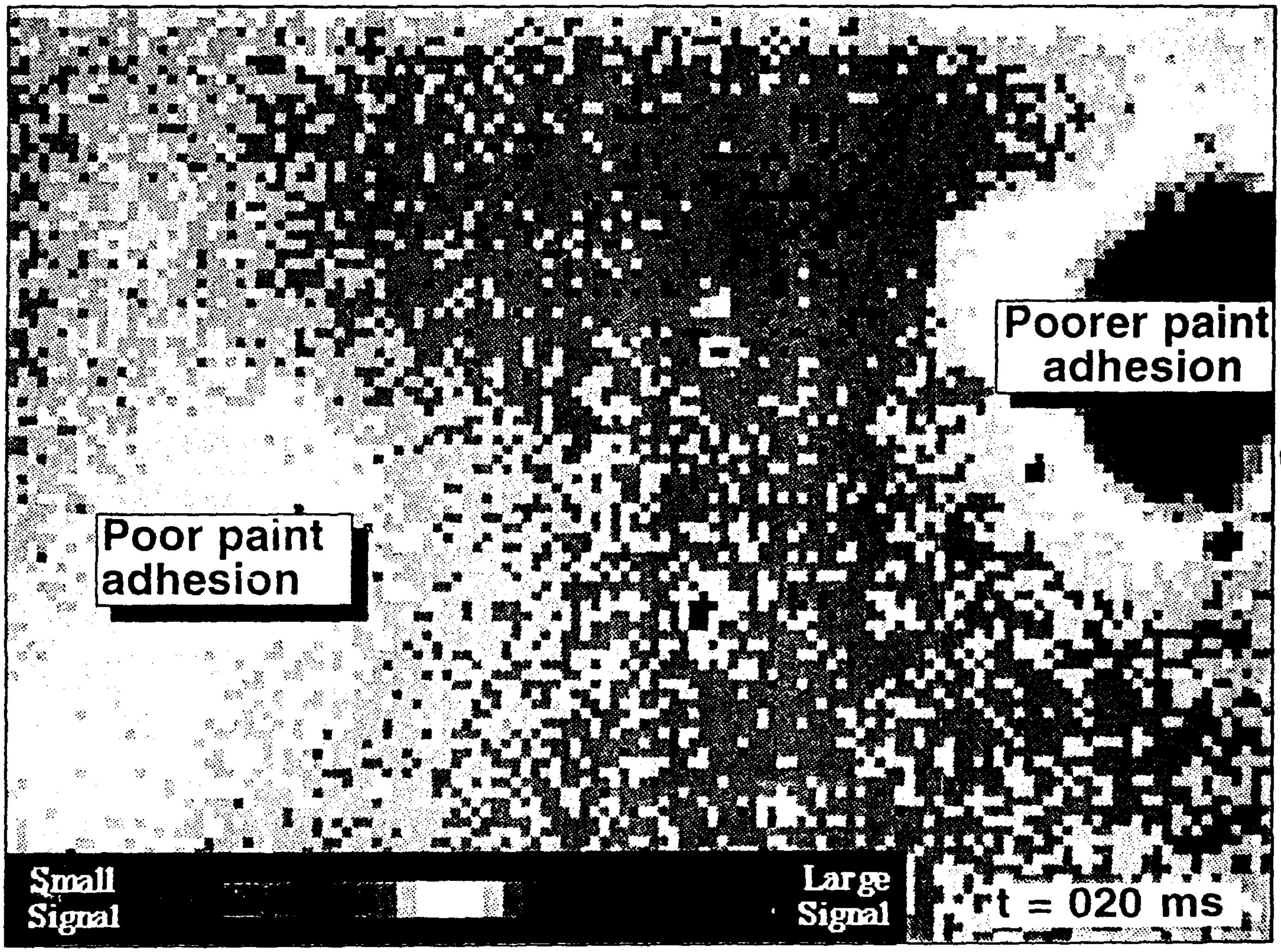


Contrast Curves: Background (T vs. t) subtracted from the (T vs. t) for the regions 1 - 6

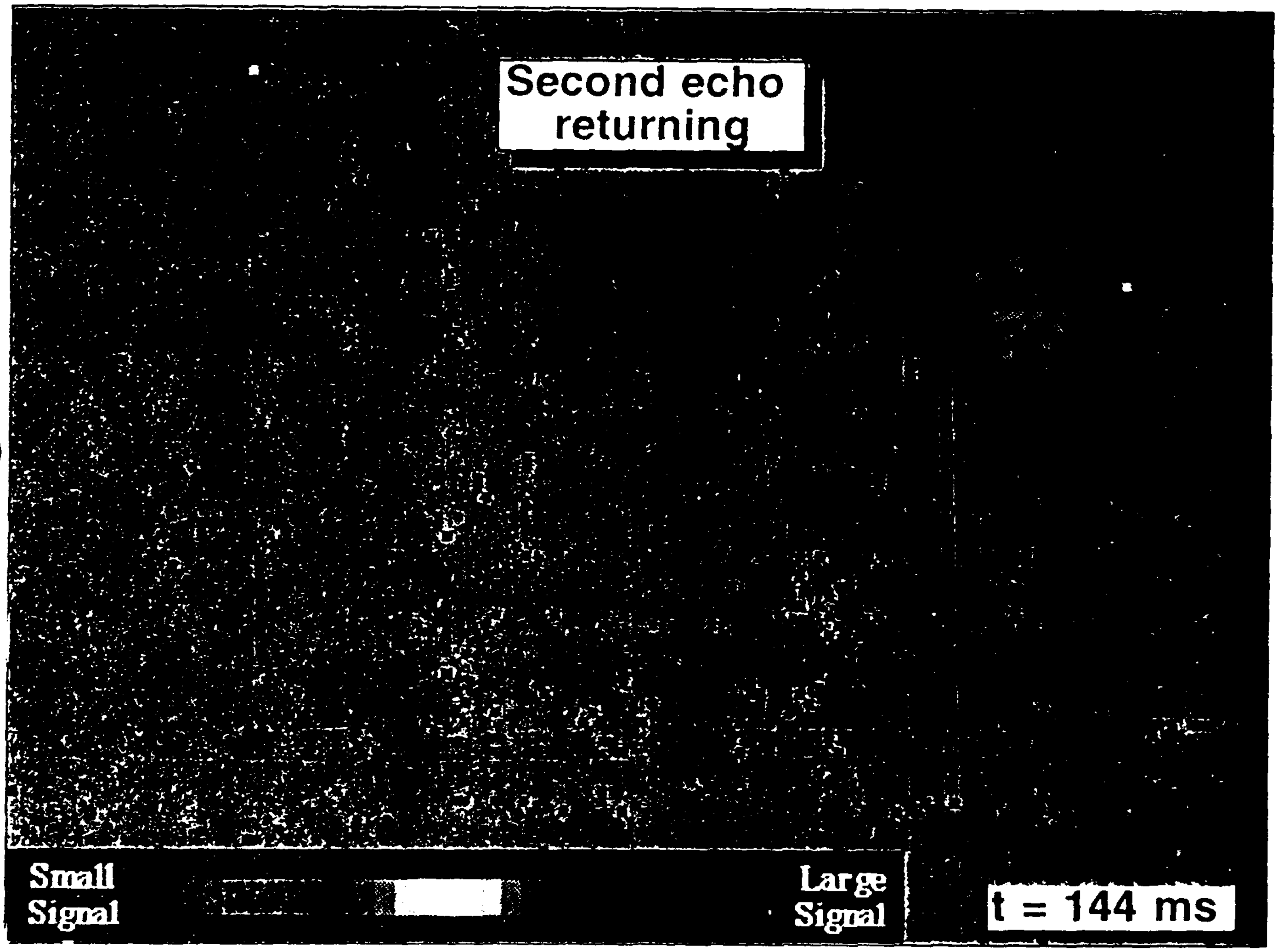

before the flash
Note the cool (blue) background
Small Signal
Large Signal

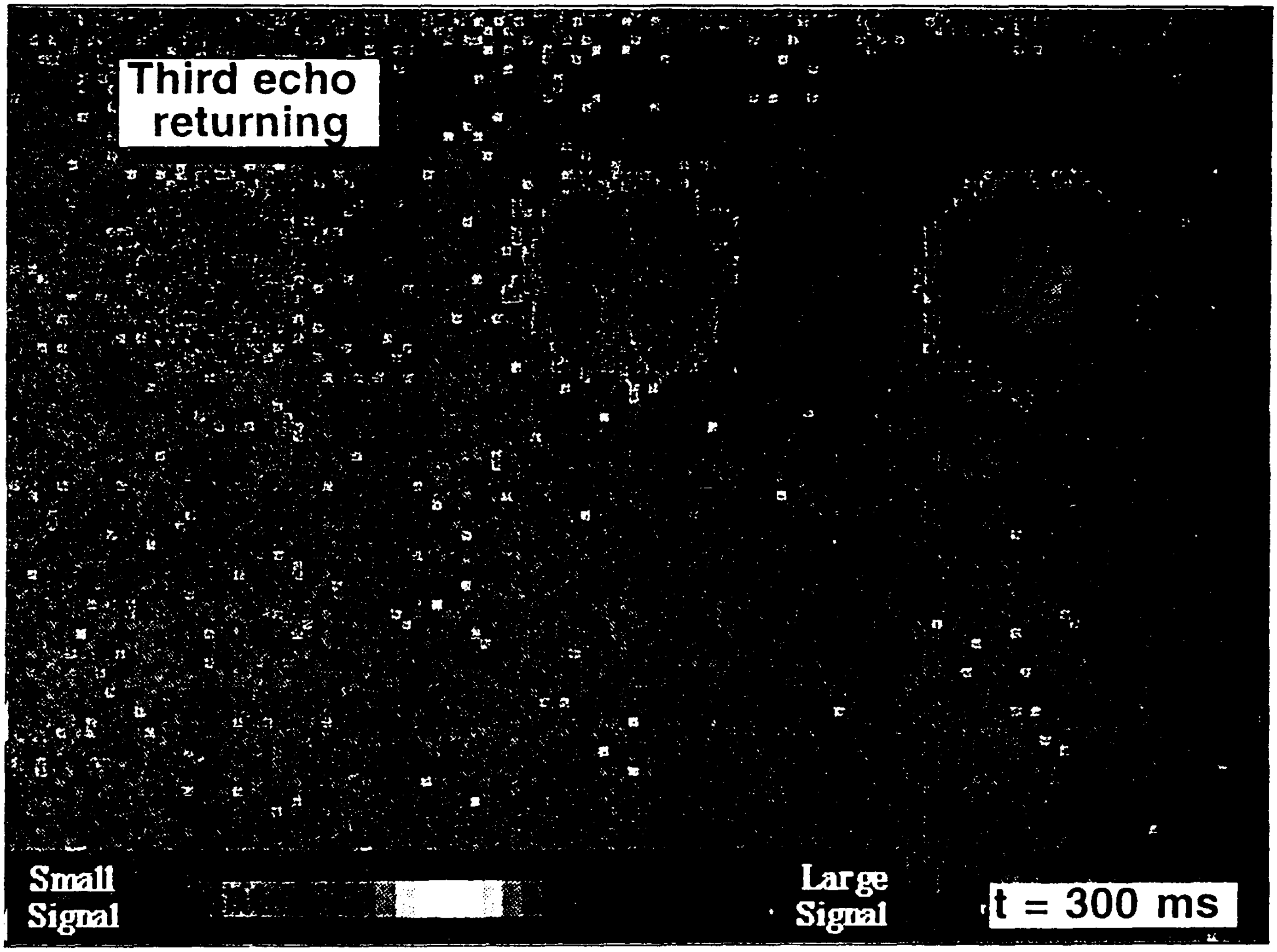

after the flash
All pixels of the FPA
are still saturated
Small
Signal
Large
Signal
t = 004 ms


Poorer paint adhesion
Poor paint adhesion
Small Signal
Large Signal
t = 012 ms



Poorer paint adhesion
Poor paint adhesion
Small Signal
Large Signal
rt = 020 ms


Second echo
returning
Small
Signal
Large
Signal
t = 144 ms


Third echo returning
Small Signal
Large Signal
t = 300 ms

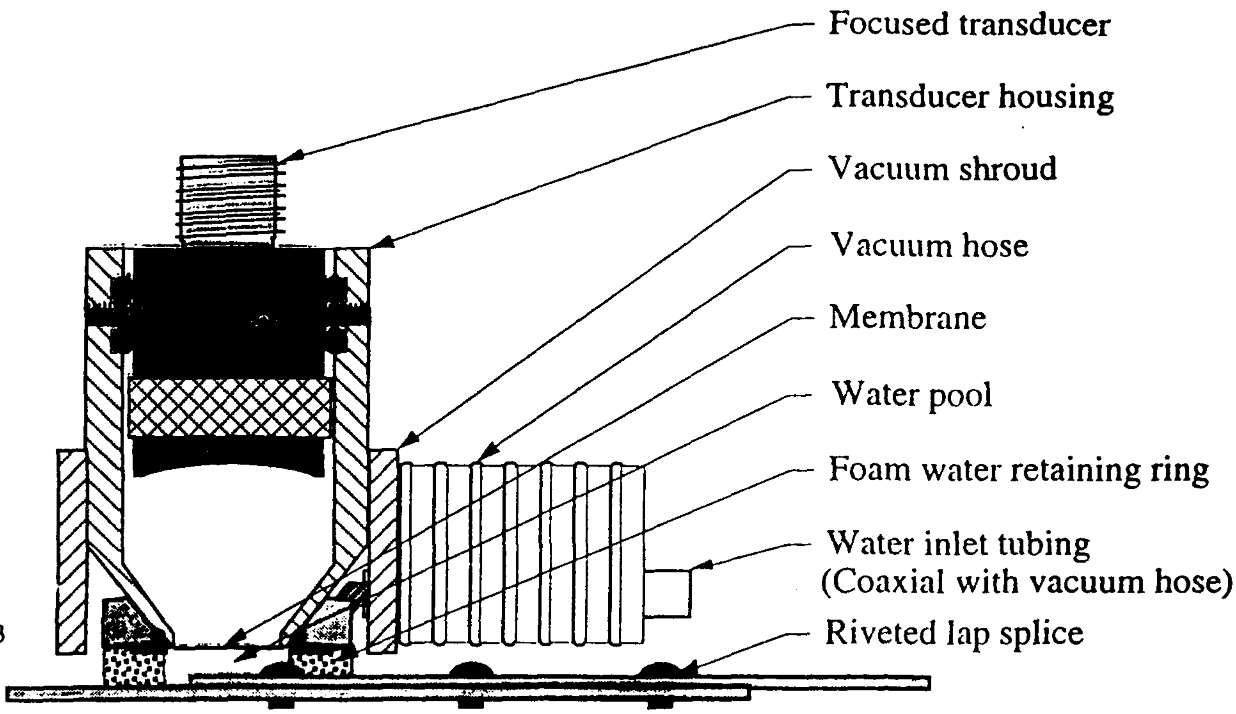
TECHNIQUES FOR FLAW DETECTION
RPI 199

Tech Area: Adhesively Bonded and Composite Structure

Ultrasonic Characterization of Adhesive Bonds

Dr. David Hsu
Iowa State University

Schematic of Dripless Bubbler

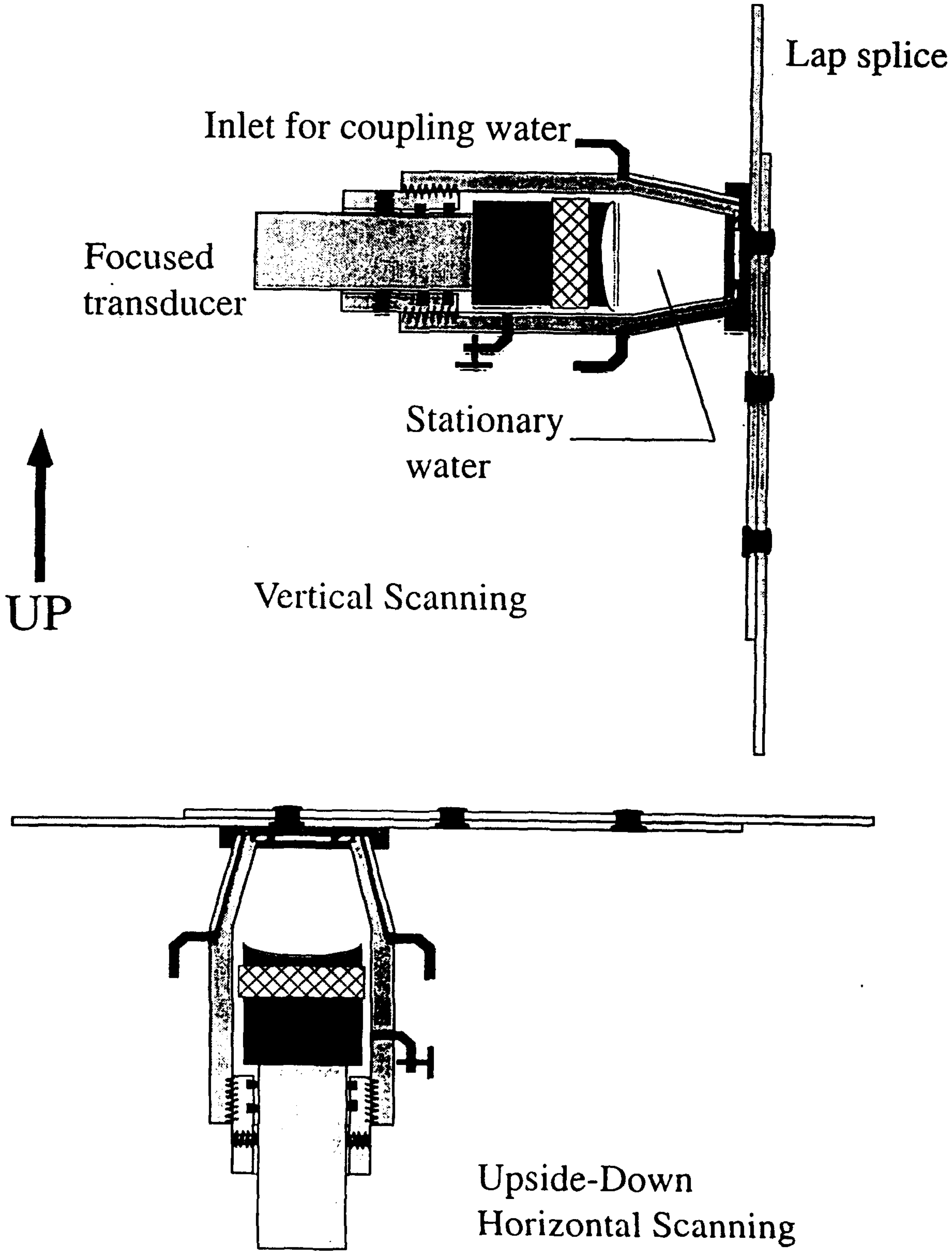


7/7/93

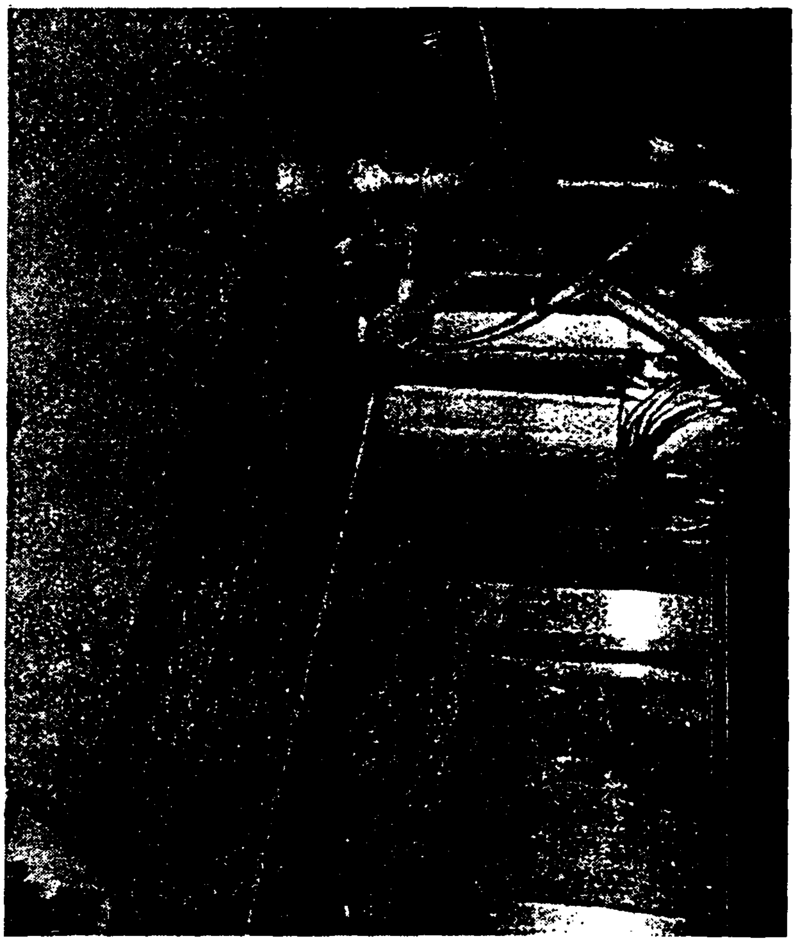
The dripless bubbler is a closed-cycle, water-coupled ultrasonic inspection method using focused transducers. It is more robust against interference fringes caused by thickness variation of bondline and paint. It is capable of scanning areas containing surface protrusions, such as button-head rivets.

Dripless Bubbler Scanning Orientations

(Vacuum attachment not shown)



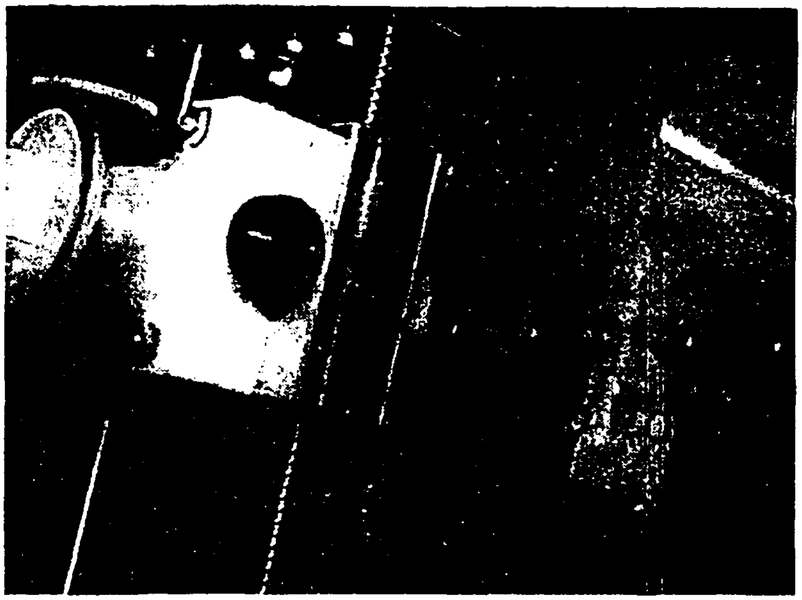
Scanning a vertical Boeing lap splice with "Dripless Bubbler" developed under FAA-CASR



The device allows focused beam ultrasonic C-scans based on amplitude and time of flight for corrosion and disbond detection.

It features a closed-cycle water pump and vacuum and can be operated on vertical or overhead surfaces. Scans can be made over surface protrusions, such as buttonhead rivets.

Field Trial on Boeing 747 at Northwest Airlines



Motorized Scanner with Dripless Bubbler
Notice top row of 1/2" dia. buttonhead rivets

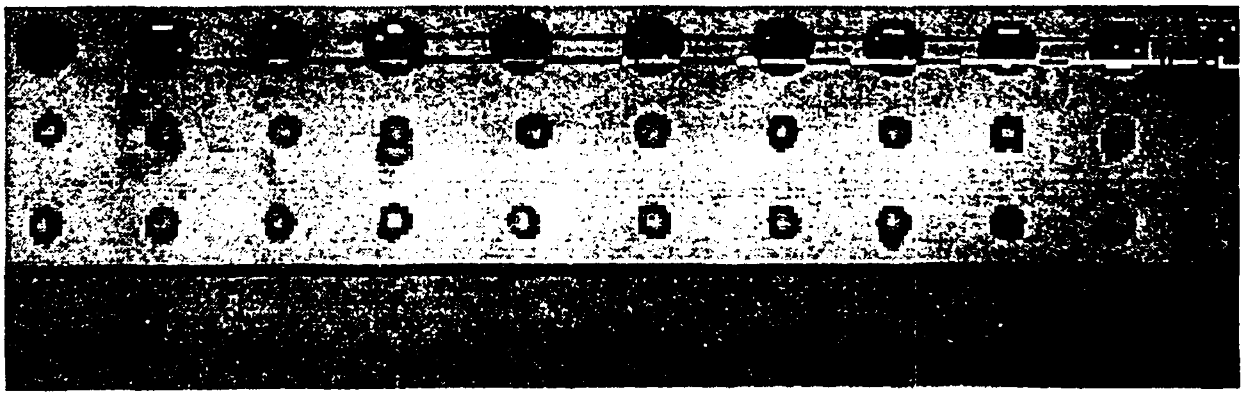
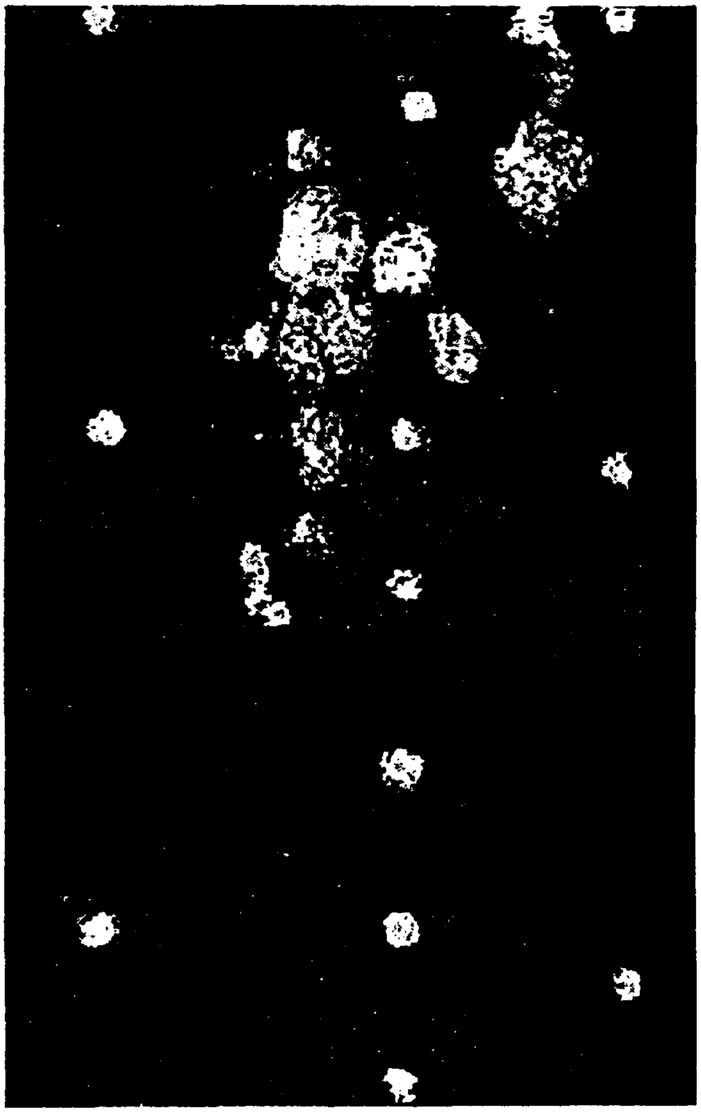


Image acquired with 1 MHz, 1" focus probe
Scan area = 12.5" x 4", step size 0.025"

Ultrasonic Time-of-Flight Scan of Corrosion in Boeing Sample VI



Pulse-echo using 15 MHz, 0.5" diam., 3" focus probe
Scan area = 5" x 8", step size = 0.025"
Circles of equal size are rivets, light gray regions are corrosion

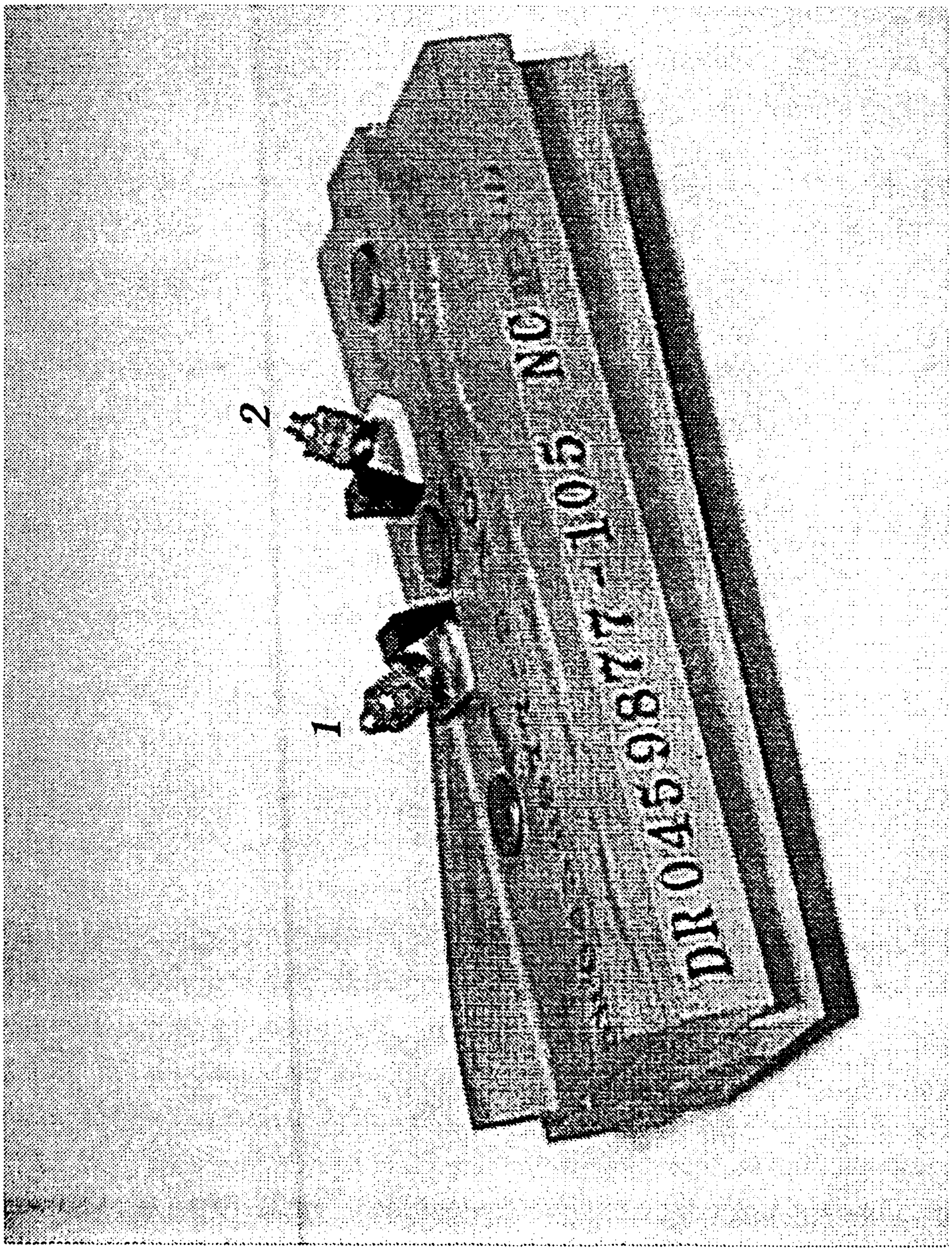
File Name BC-VI-2.CS8

NDI RELIABILITY
RPI 205

Tech Area: NDE Equipment Research

Self-Compensating Ultrasonic Instrument

Dr. J. D. Achenbach
Northwestern University


1
2

TECHNIQUES FOR FLAW DETECTION
RPI 199

Tech Area: Adhesively Bonded and Composite Structure

Optical Interferometry

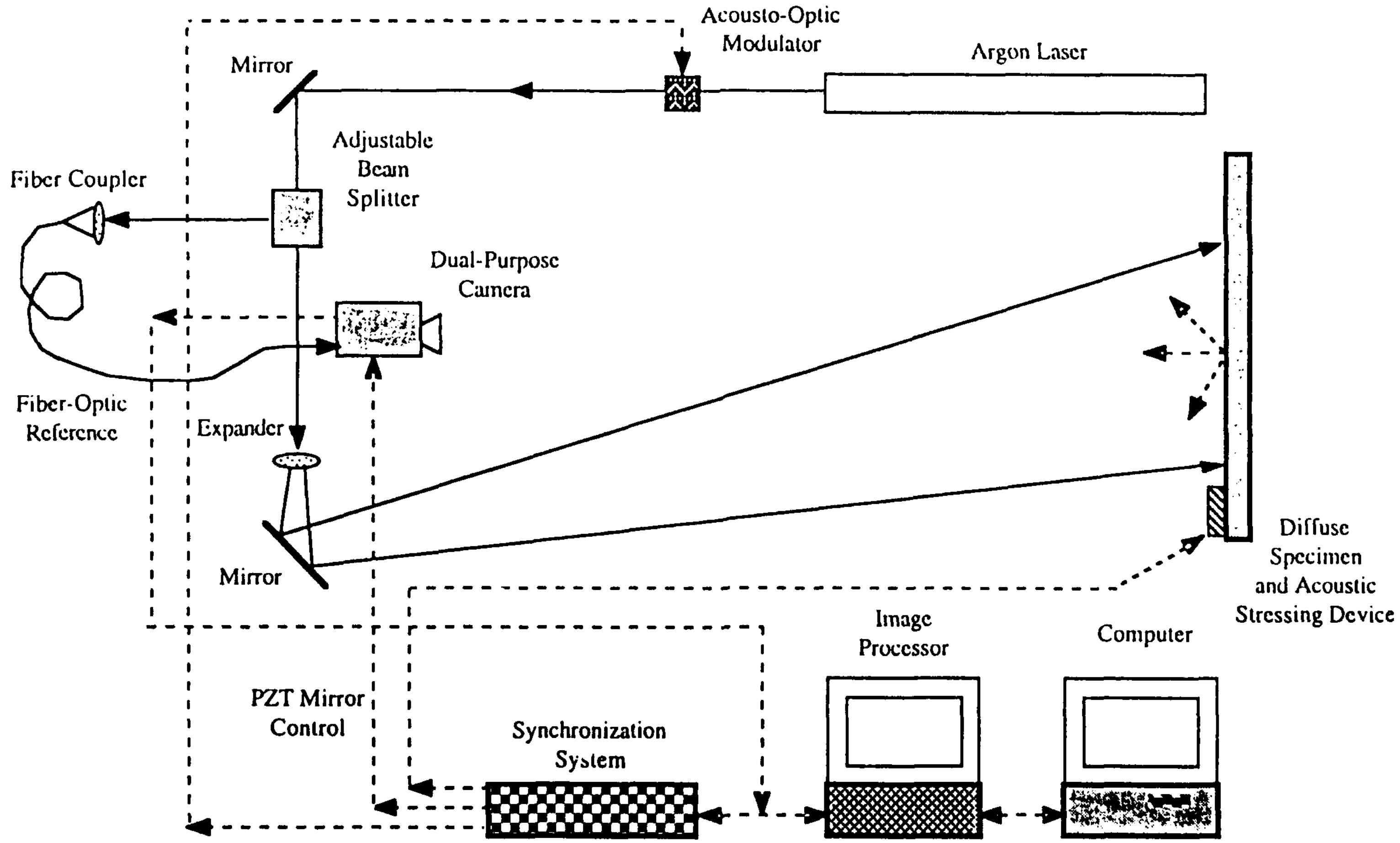
Dr. Sridhar Krishnaswamy
Northwestern University

EFFECT OF AMB‌IENT NOISE ON SPECKLE INTERFEROMETRY

SOURCE	TYPE	EFFECT
OBJECT DRIFT (eg: settling of landing gear)	SLOW LARGE AMPLITUDE	DECORRELATION
STRUCTURAL VIBRATIONS (eg: machinery)	LOW FREQUENCY MEDIUM AMPLITUDE	DECORRELATION & PHASE SHIFTS
THERMAL NOISE (eg: air-conditioning ducts)	HIGH FREQUENCY SMALL AMPLITUDE	PHASE SHIFTS

- DECORRELATION $\Rightarrow$ SIGNATURE LOSS
- PHASE SHIFTS $\Rightarrow$ SIGNATURE DISTORTION

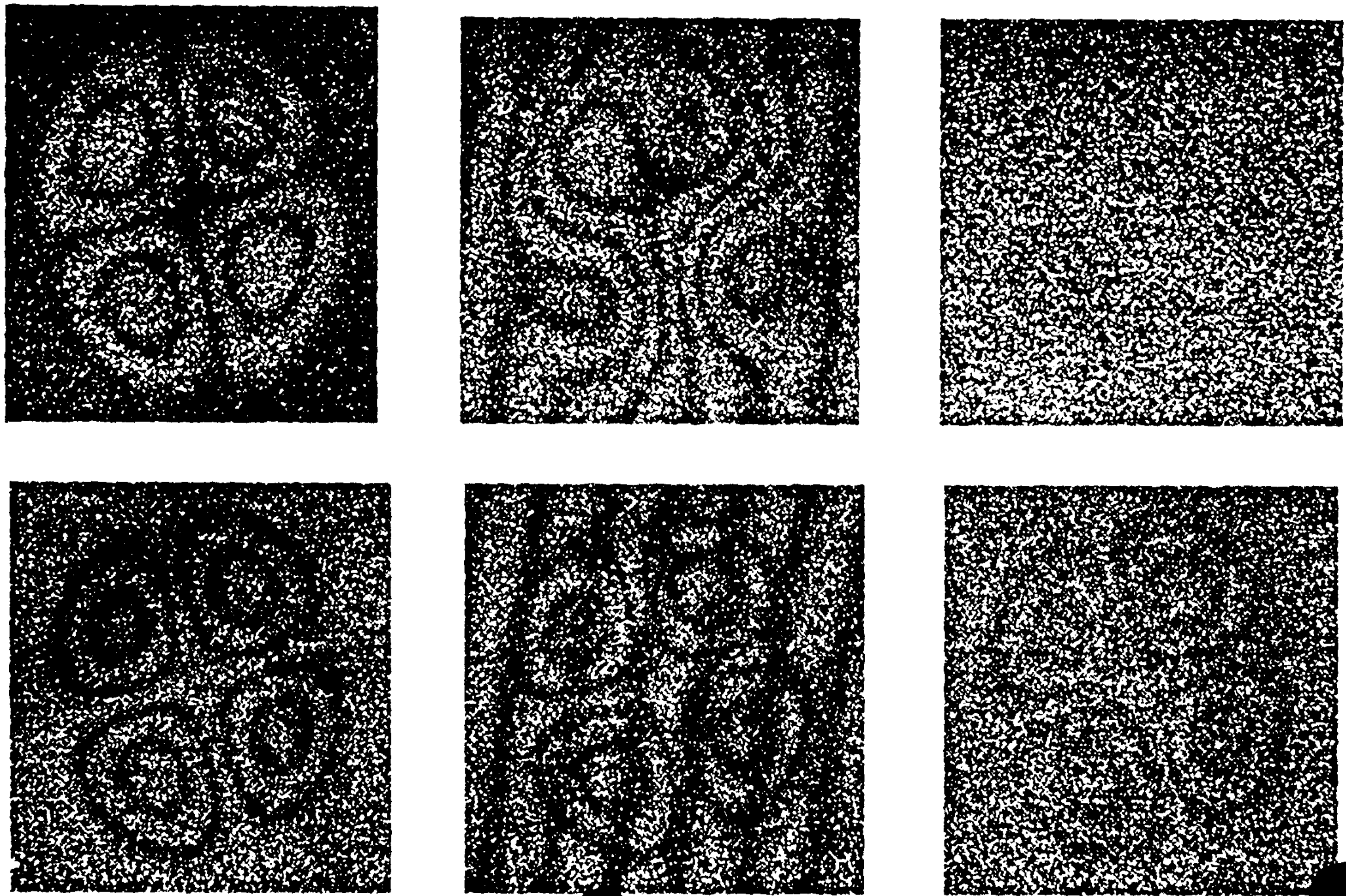
EXPERIMENTAL MINIATURE CAMERA SETUP



STUDY OF FRINGE VISIBILITY WITH TRANSLATION-INDUCED DECORRELATION

CONVENTIONAL ESPI

ASPM-ESPI



INDUSTRIAL INTERACTION

- PATENT LICENSE WITH LASER TECHNOLOGY INC.
  - MODIFYING IMAGE PROCESSING ALGORITHMS TO PERFORM REFERENCE UPDATING.
  - INCORPORATING SYNCHRONIZED STROBOSCOPIC ILLUMINATION.
  - APPLY PHASE MODULATION UTILIZING ELECTRO-OPTIC OR TRANSLATING MIRROR DEVICES.
  - SWITCHING OVER TO ESPI FROM SHEAROGRAPHY.

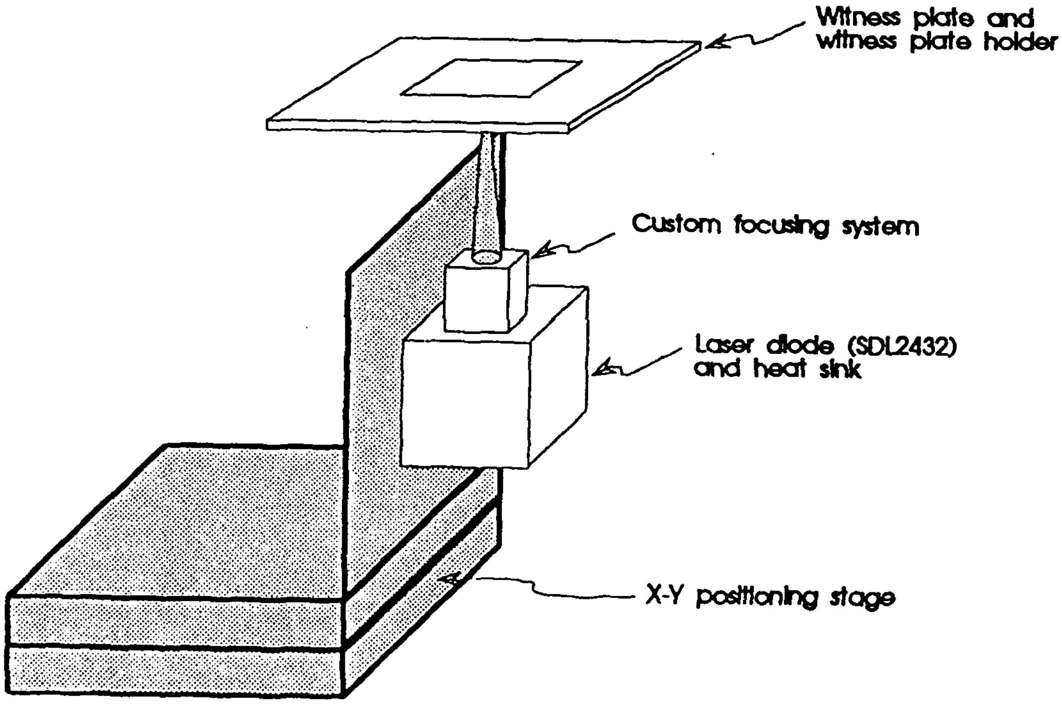
NDI RELIABILITY
RPI 205

Tech Area: NDE Equipment Research

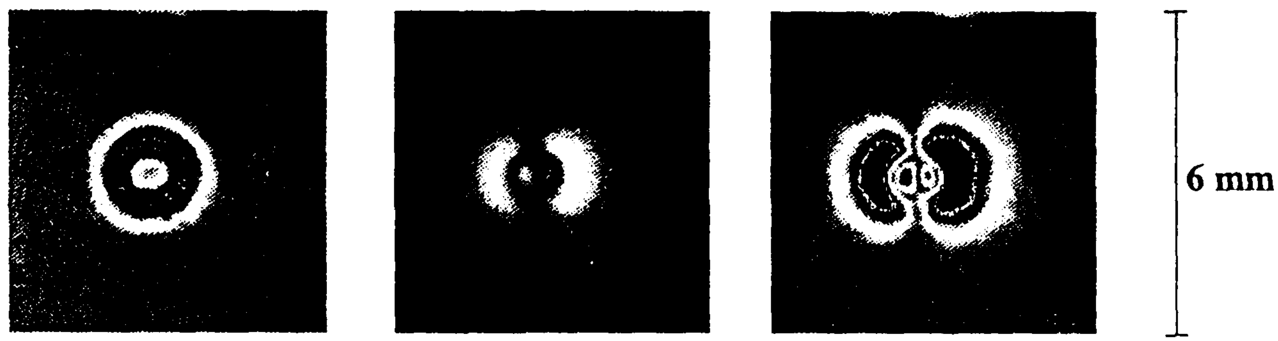
Eddy Current Probe Calibration and Standardization

John Moulder
Iowa State University

Eddy Current Probe Calibrator



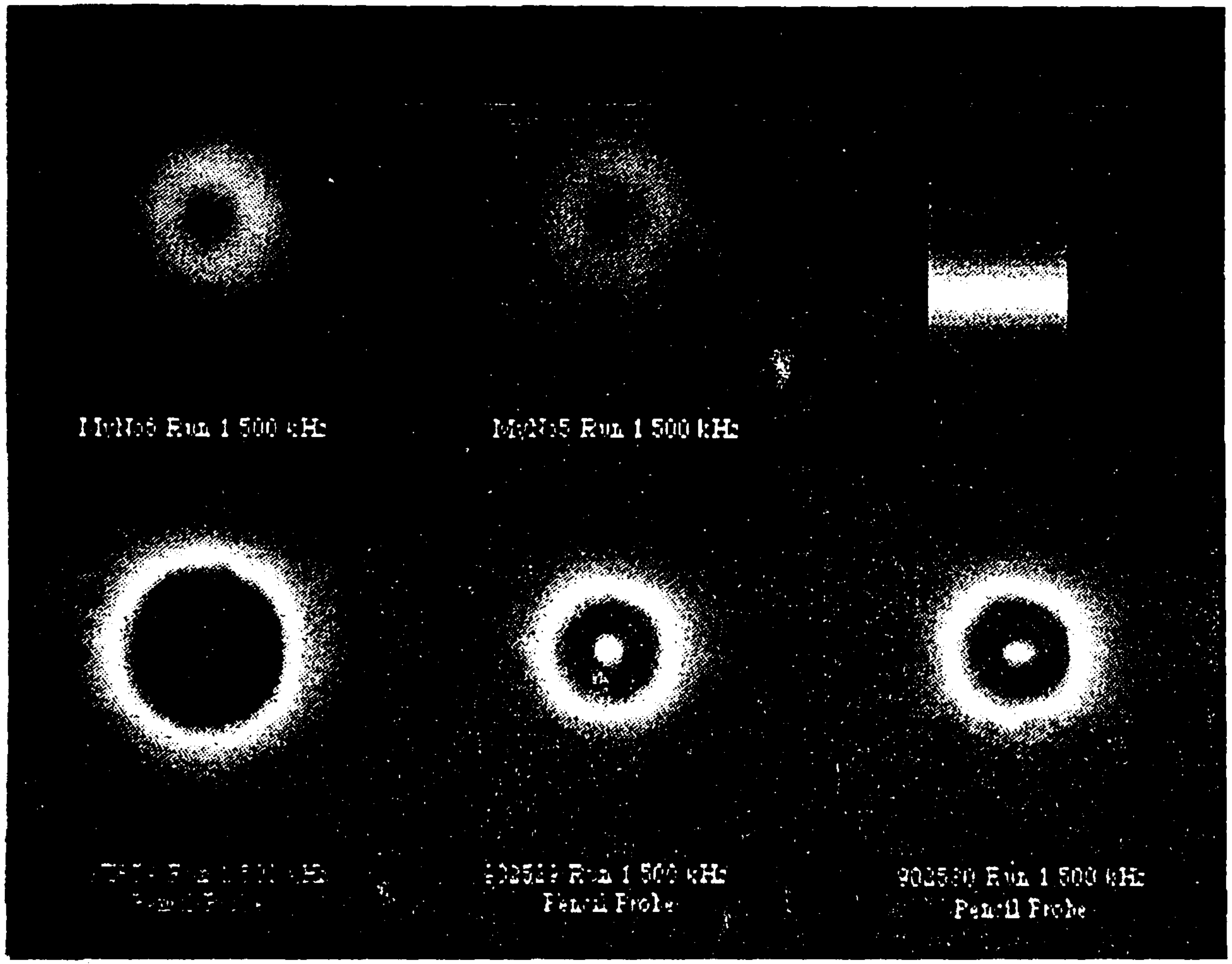
2 MHz Reflection Probe



Drive Coil | Pickup Coil | Combination (reflection probe)

Eddy Current Probe Calibrator Field Demo at NWA

Photoinductive Maps of Nominally Identical 500 kHz Absolute Probes



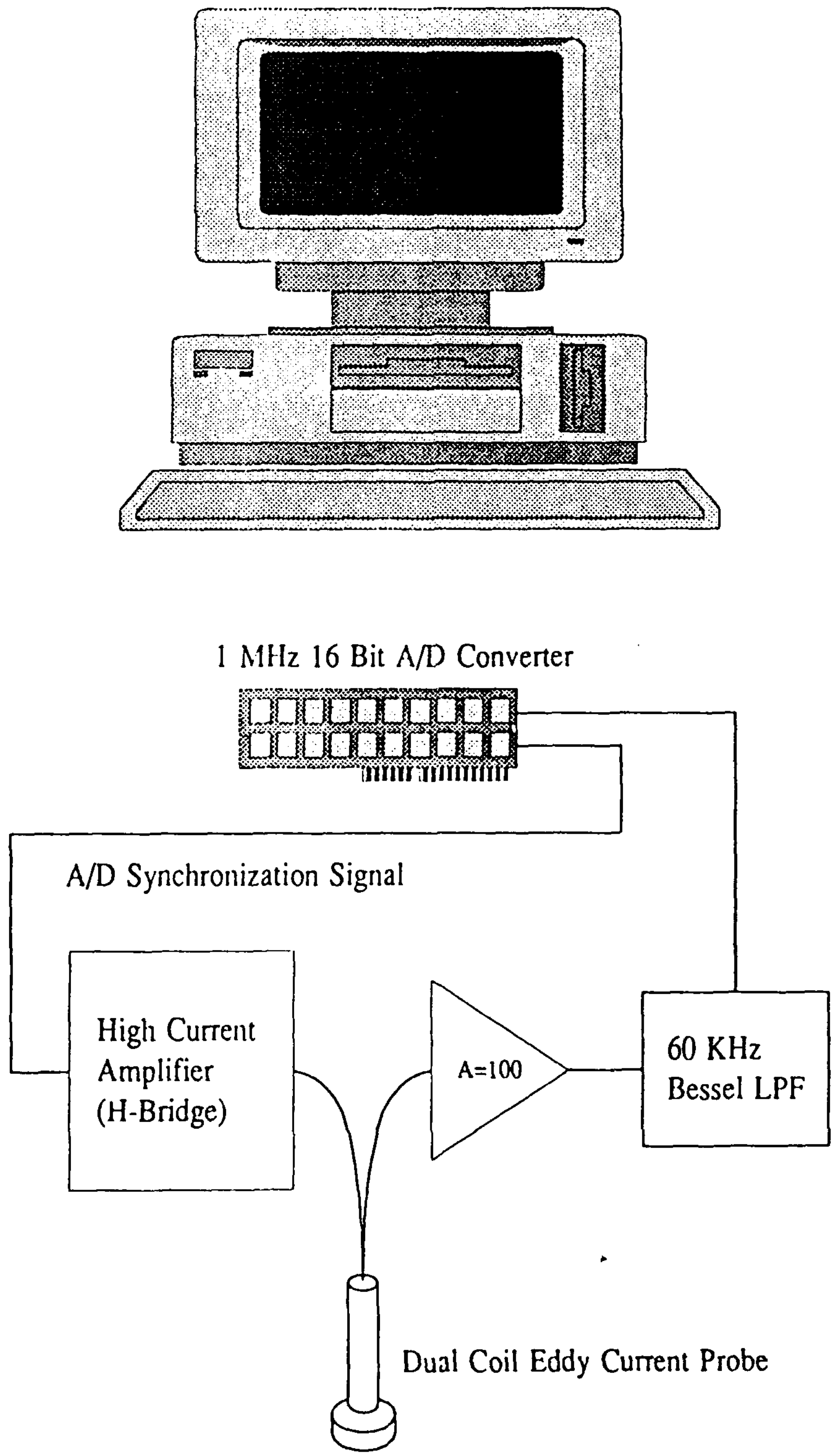
NDI RELIABILITY
RPI 205

Tech Area: NDI for Corrosion Detection

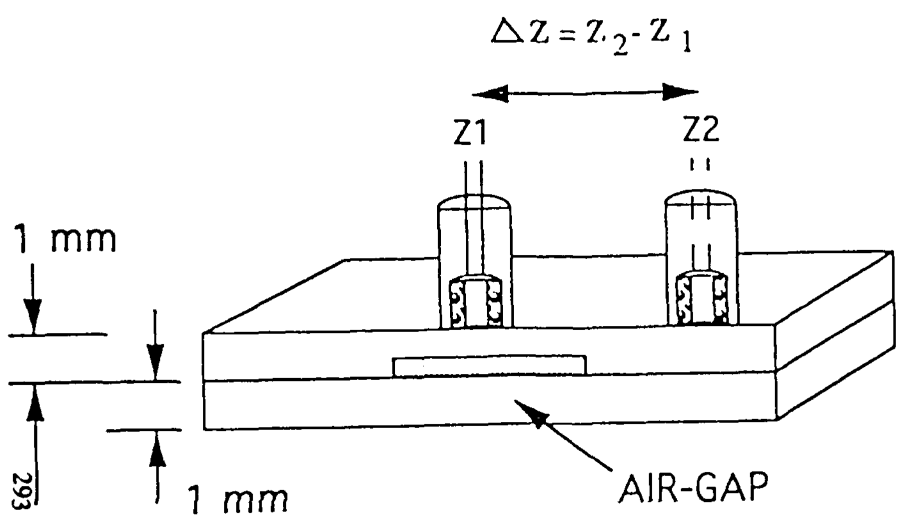
Pulsed Eddy Current for Detection of Second Layer Corrosion

John Moulder
Iowa State University

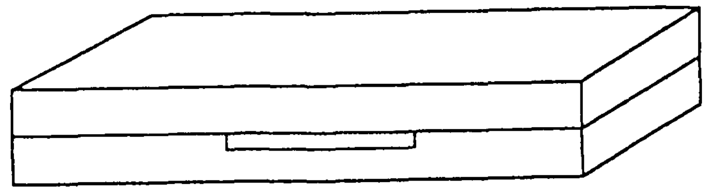
Block Diagram of 16-Bit High Speed Pulsed Eddy Current Apparatus



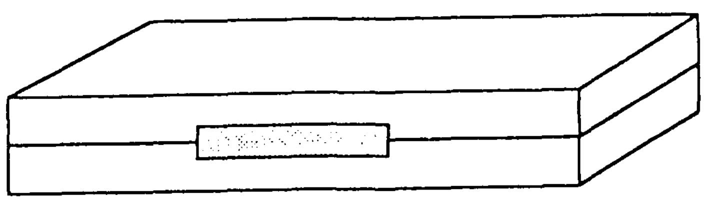
TOP PLATE THINNED



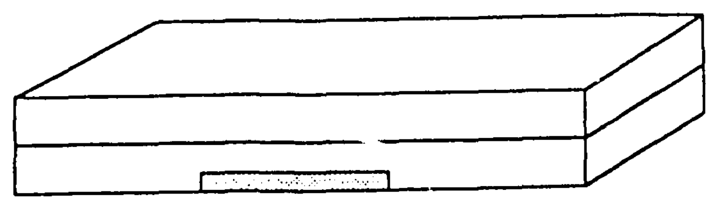
BOTTOM PLATE THINNED



BOTH PLATES THINNED

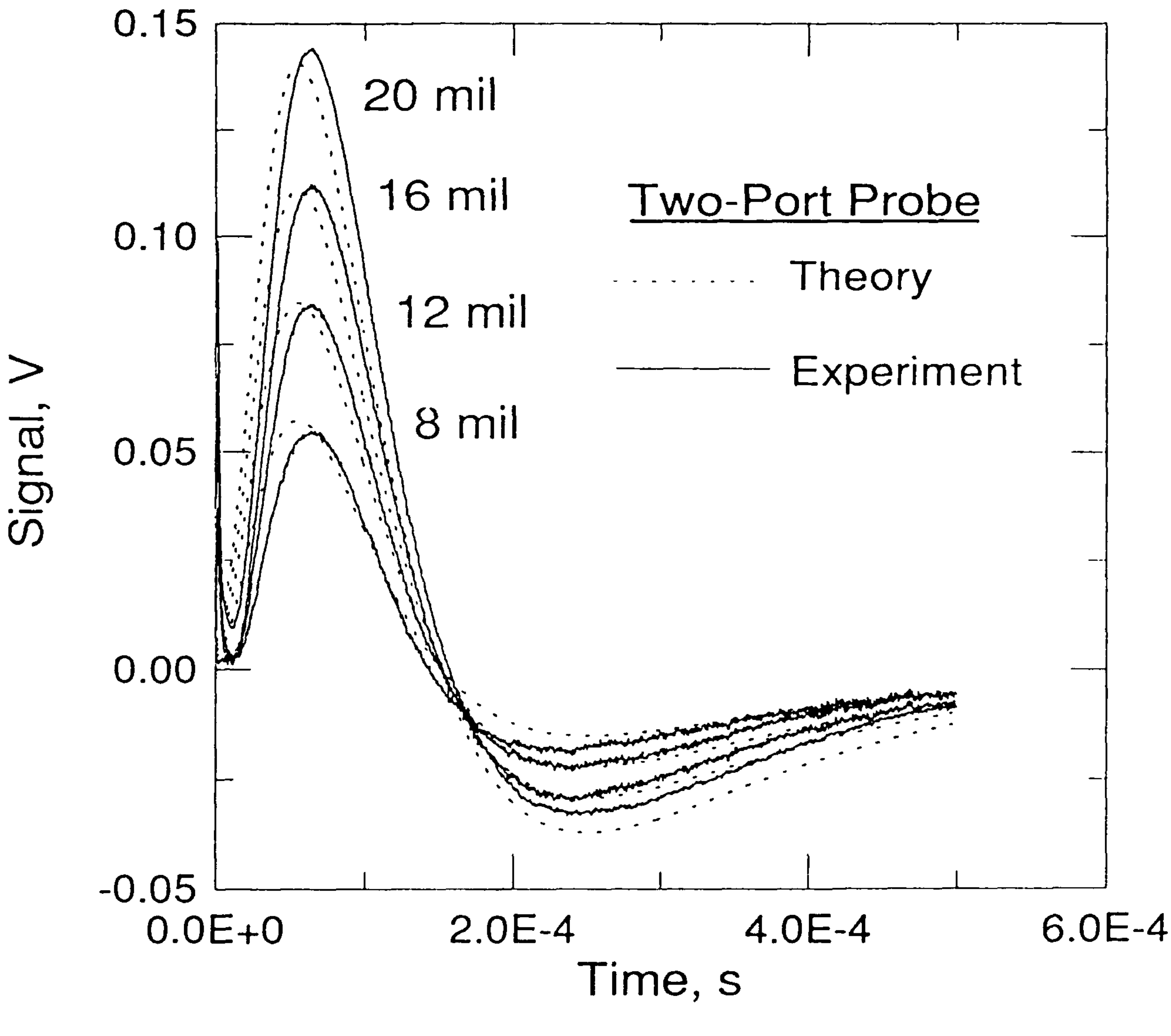


BOTTOM SURFACE THINNED



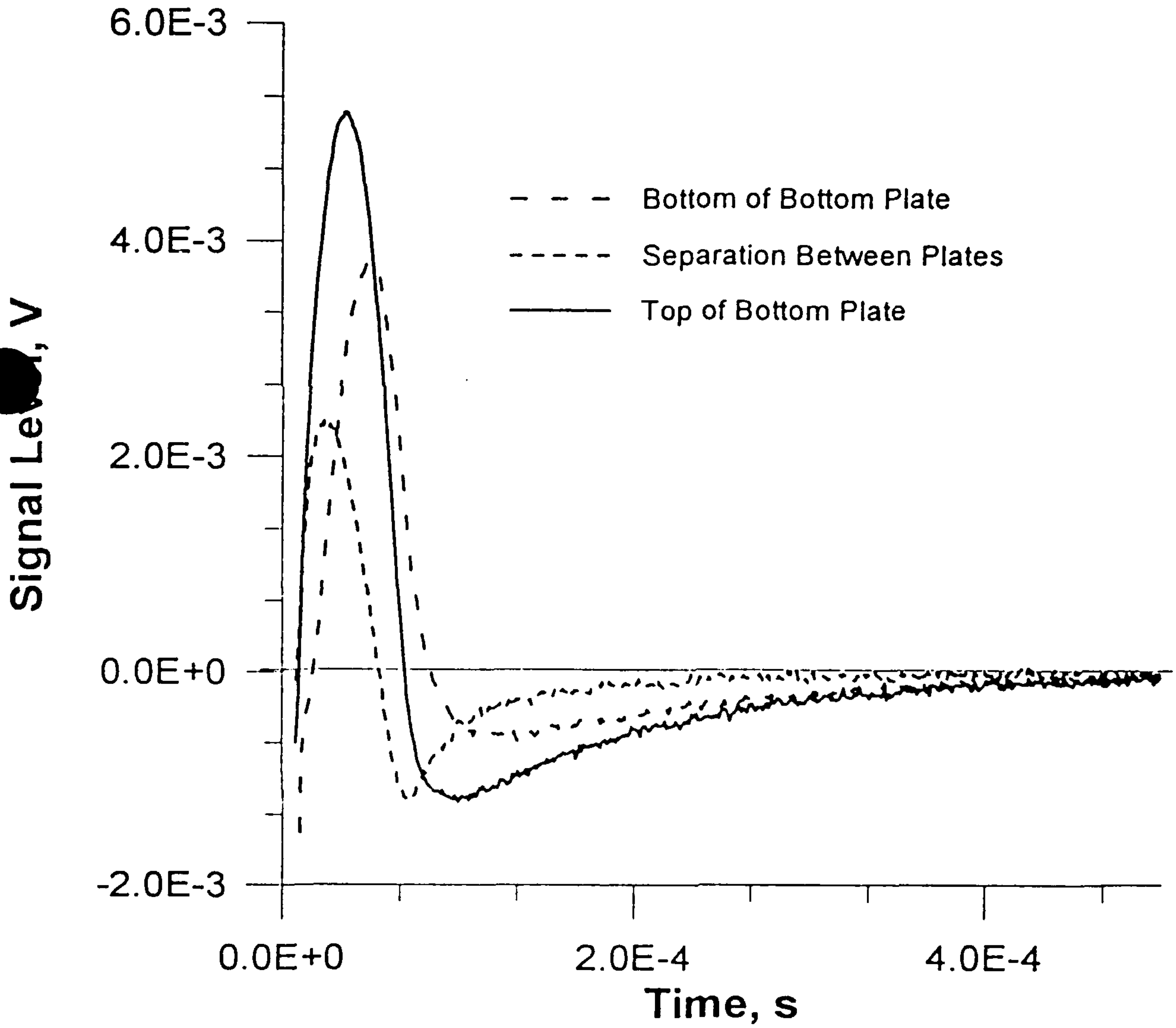
Pulsed Eddy Current Theory and Experiment

Simulated Corrosion in Second Layer

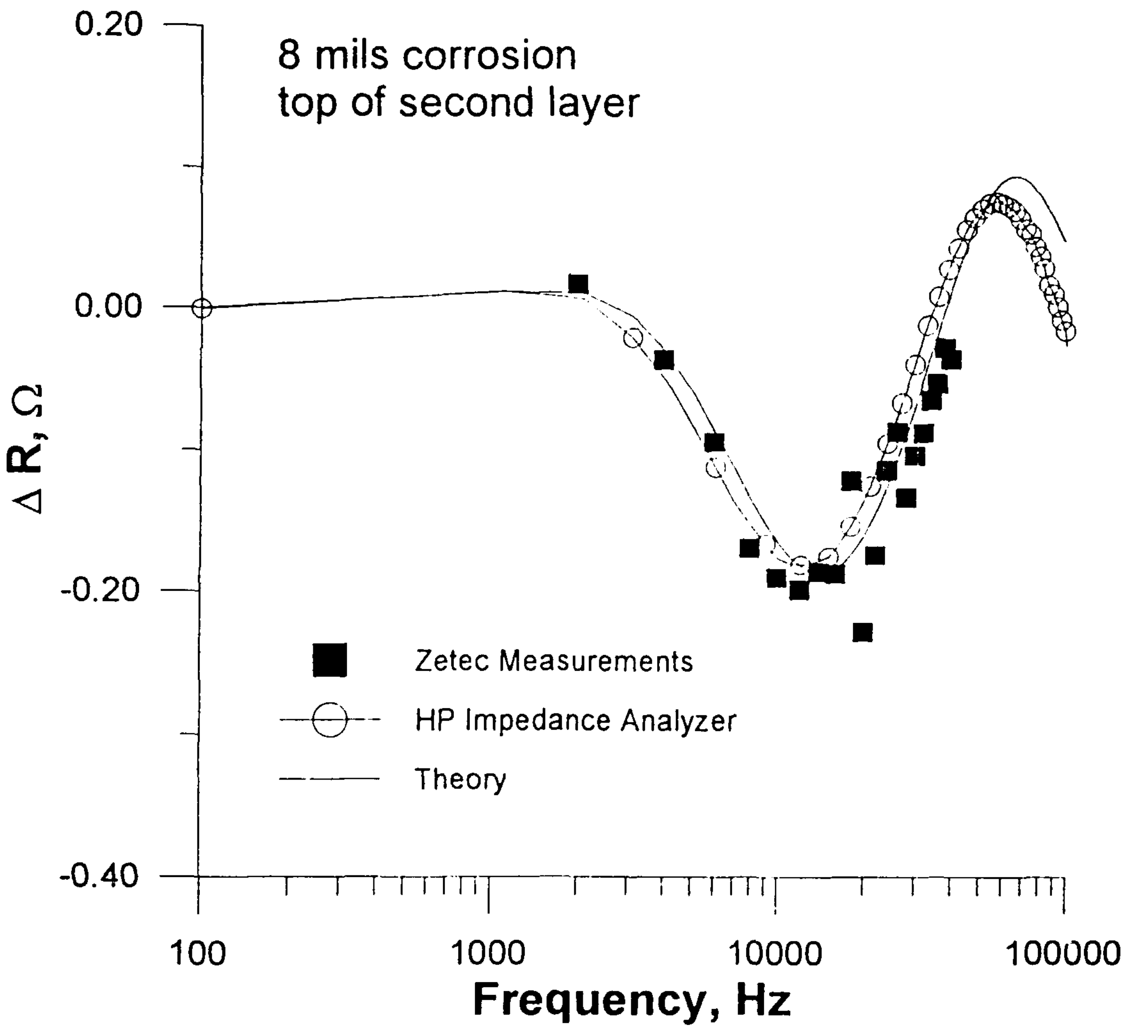


FAA CASR

Plate Separation Compared to Simulated Corrosion (4 mils)



Zetec Eddy Current Instrument vs. HP Impedance Analyzer

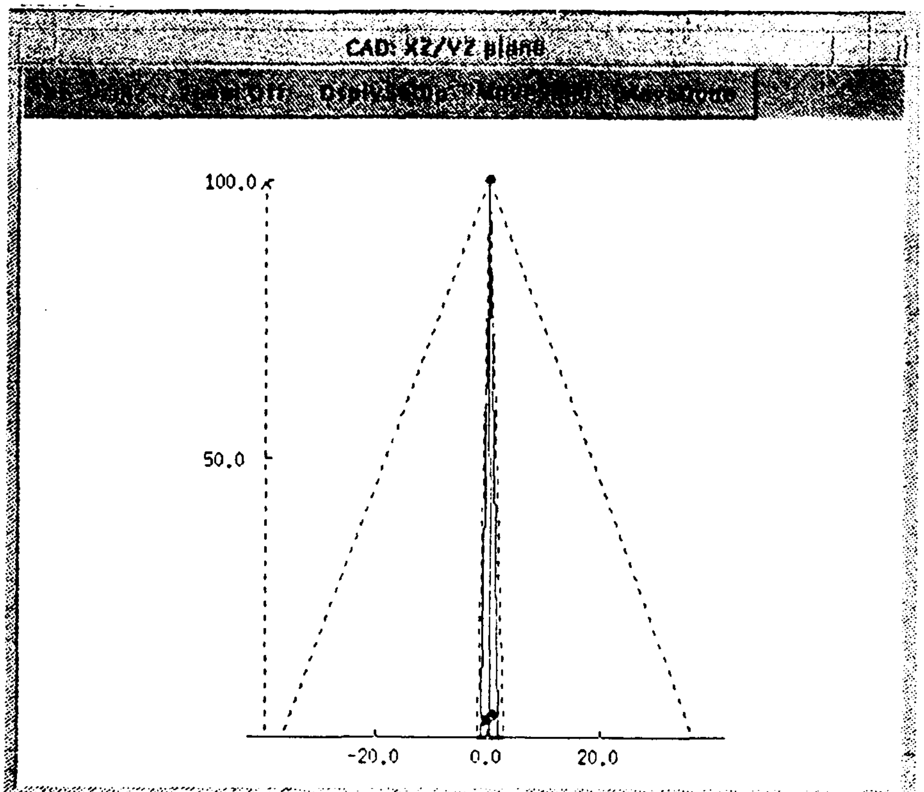


INSPECTION RELIABILITY
RPI 205

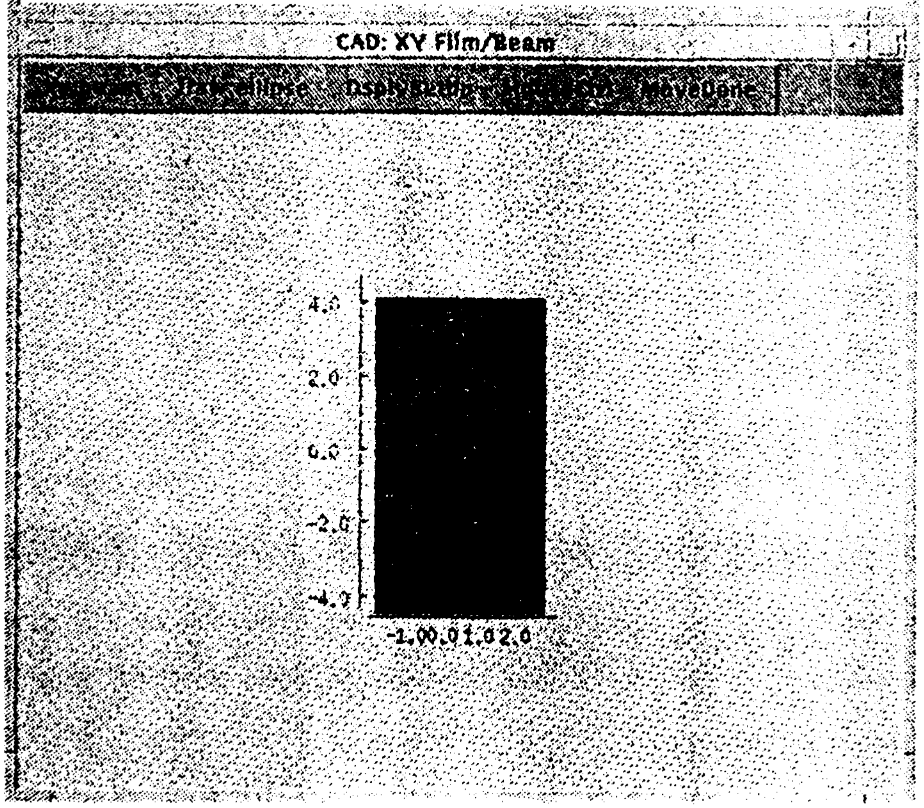
Tech Area: Inspection Simulator

X-ray Module

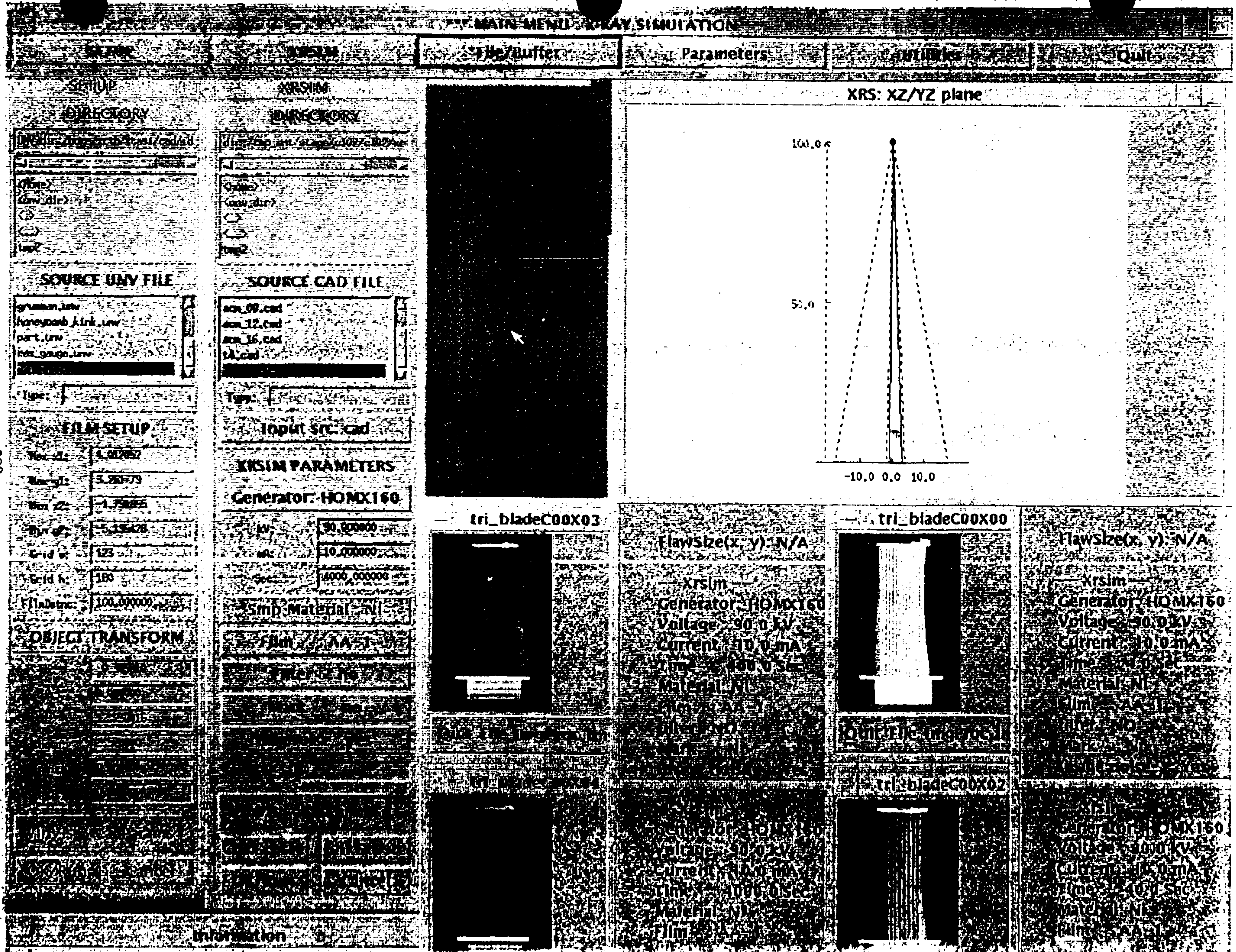
Dr. Joseph Gray
Iowa State University

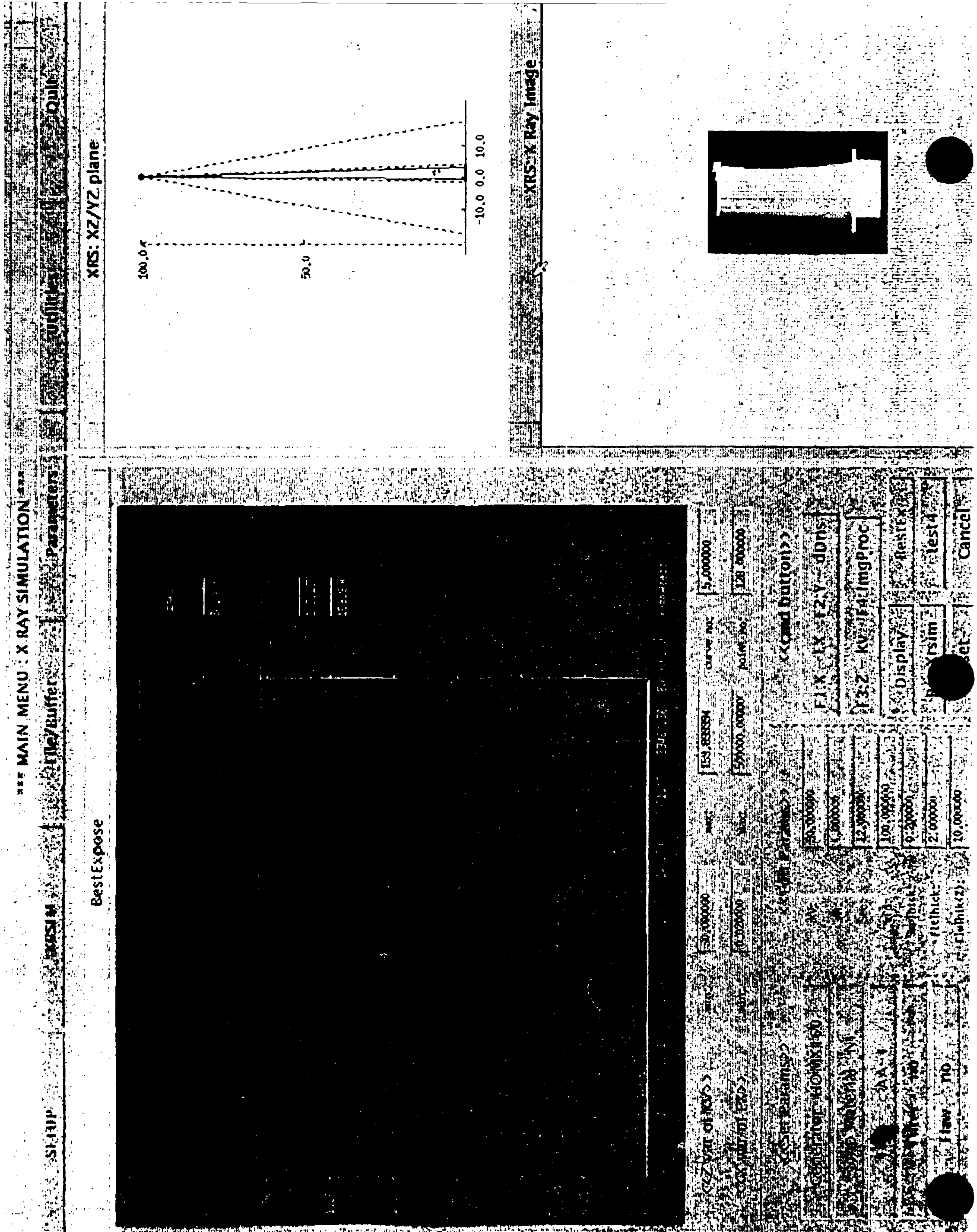


CAD: XZ/YZ plane
100.0
50.0
-20.0
0.0
20.0



CAD: XY Film/Beam
4.0
2.0
-2.0
-4.0


MAIN MENU X-RAY SIMULATION
File/Buffer
Parameters
Quits
SETUP
DIRECTORY
SOURCE UNV FILE
FILM SETUP
OBJECT TRANSFORM
XRSIM
SOURCE CAD FILE
Input src. cad
XRSIM PARAMETERS
Generator: HOMX160
Information
XRS: XZ/YZ plane
100.0
50.0
-10.0 0.0 10.0
tri_bladeC00X03
tri_bladeC00X00
tri_bladeC00X02
FlawSize(x, y): N/A
Xrsim
Generator: HOMX160
Voltage: 90.0 kV
Current: 10.0 mA
Material: NI


*** MAIN MENU : X RAY SIMULATION ***
SETUP
XRSIM
File/Buffer
Parameters
Utilities
Quit
BestExpose
XRS: XZ/YZ plane
XRS: X Ray Image
<<cmd button>>
Display
Cancel

NDI AUTOMATION AND ROBOTICS
RPI 200

Tech Area: Evaluation of Advanced NDE Concepts

Image Processing for Radiographic Inspection

Dr. Richard Wallingford
Iowa State University

NDI Automation and Robotics RPI 200

FAA Center for Aviation Systems Reliability

Task - Image Processing for Radiographic Inspection

<u>Status Last Year</u>:

1. Defined target problem after visit to NWA at Atlanta, Georgia
   - Real-time x-ray image enhancement in burner can insepction and other engine components

2. Defined the required capabilities and specifications fo a real-time x-ray image processor
   - Must improve inspection sensitivity and POD in *real-time*
   - Must be low-cost and easy to use
   - Must be integrable with existing airline inspection systems (add-on)

FAA/REV ISU 4-94

NDI Automation and Robotics RPI 200

FAA Center for Aviation Systems Reliability

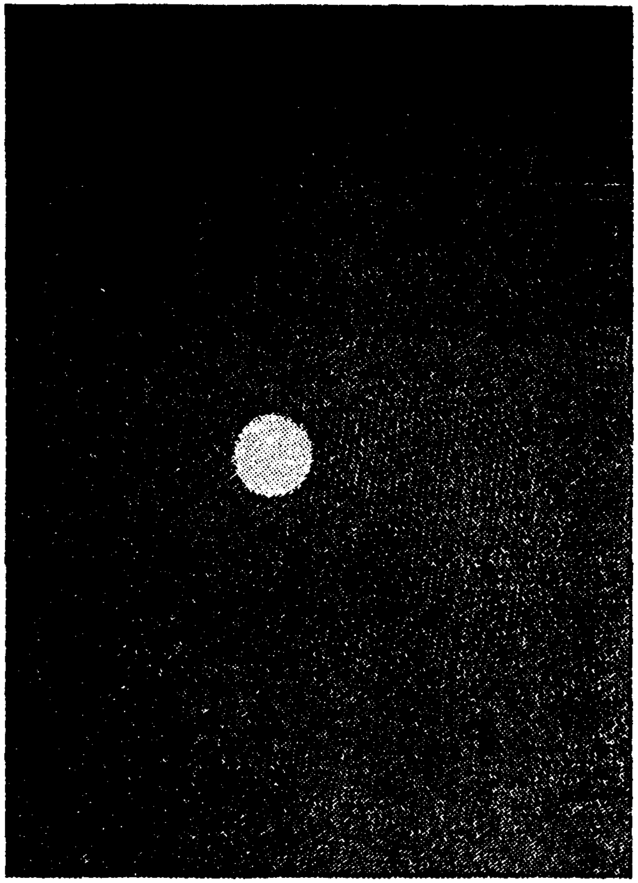
Current Status:

1. Working prototype has been assembled and successfully demonstrated on a variety of inspections:
   - Improved detectability of burner can cracking
   - Detectability of fatigue cracks under non-optimal orientation
   - Detection of porosity

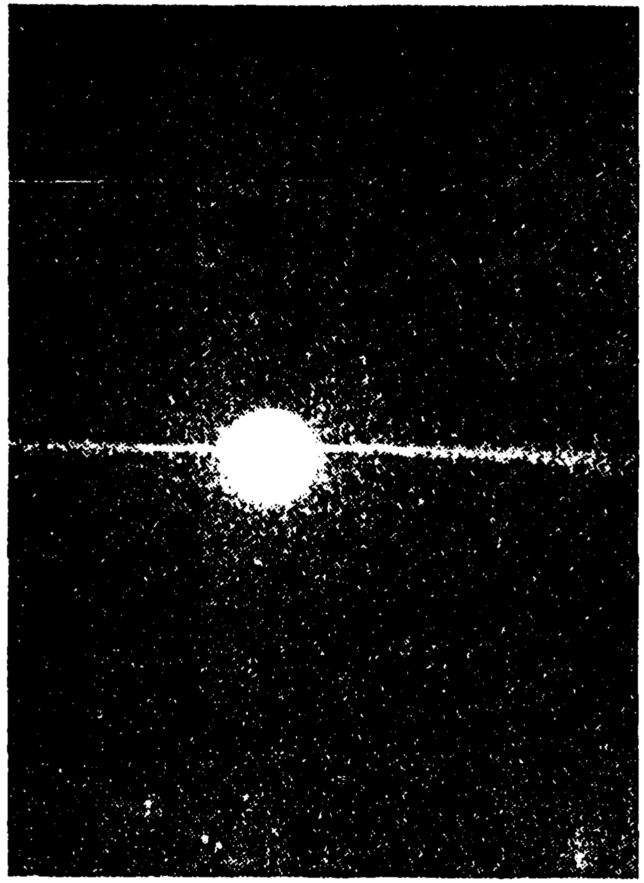
2. Positive feedback from airlines (Northwest and Delta) at recent in-house demonstration
   - Beta site evaluation planned for next few months at NWA in real-time inspection facility in Atlanta, Georgia

3. System repeatedly demonstrating a POD improvement from 0% to 100% in several detection studies. System sensitivity improved from 4% (unprocessed) to <1% (processed).

FAAREV TSU 4-94



Unprocessed



RT Processed

Typical Processing Result on Fatigue Crack Detection

NDI RELIABILITY
RPI 205

Tech Area: NDI For Corrosion Detection

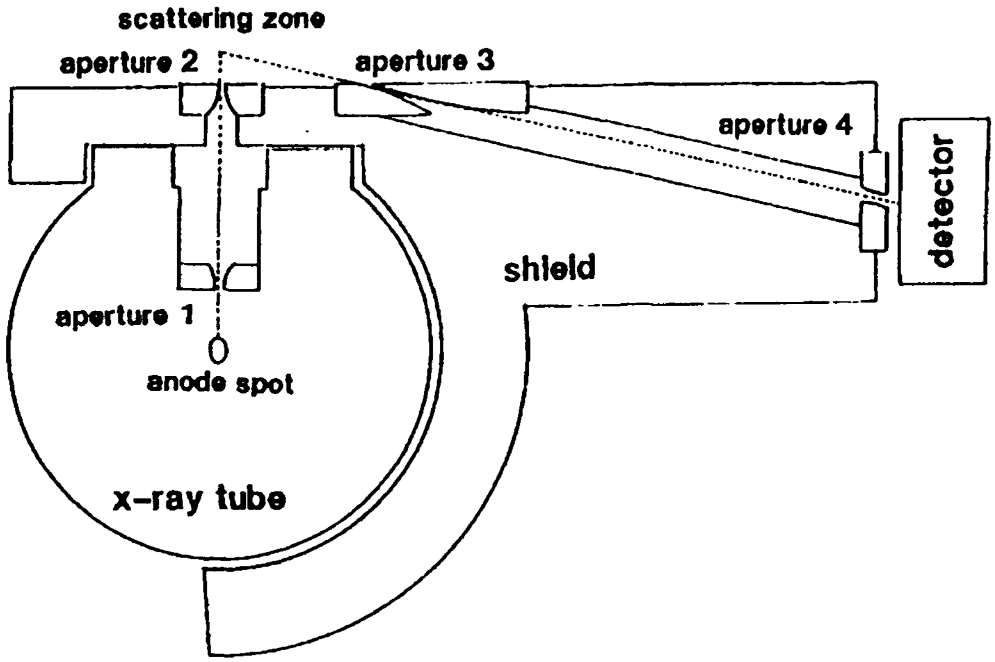
Radiographic Methods for Corrosion Detection

Dr. Jan Achenbach
Northwesten University

FEATURES OF COMPTON X-RAY BACKSCATTER DEPTH PROFILOMETRY

- Gives a cross-sectional view of aircraft sheet metal joints.
- Allows measurement and identification of sub-surface layers.
- 1/1000 inch measurement accuracy.
- Generates very little ambient x-radiation.
- No evacuations--Does not interfere with most hangar activity.
- Self-propelled. Scaffolding and stands are not needed.
- Data are digital files -- easily stored and transmitted via Internet.

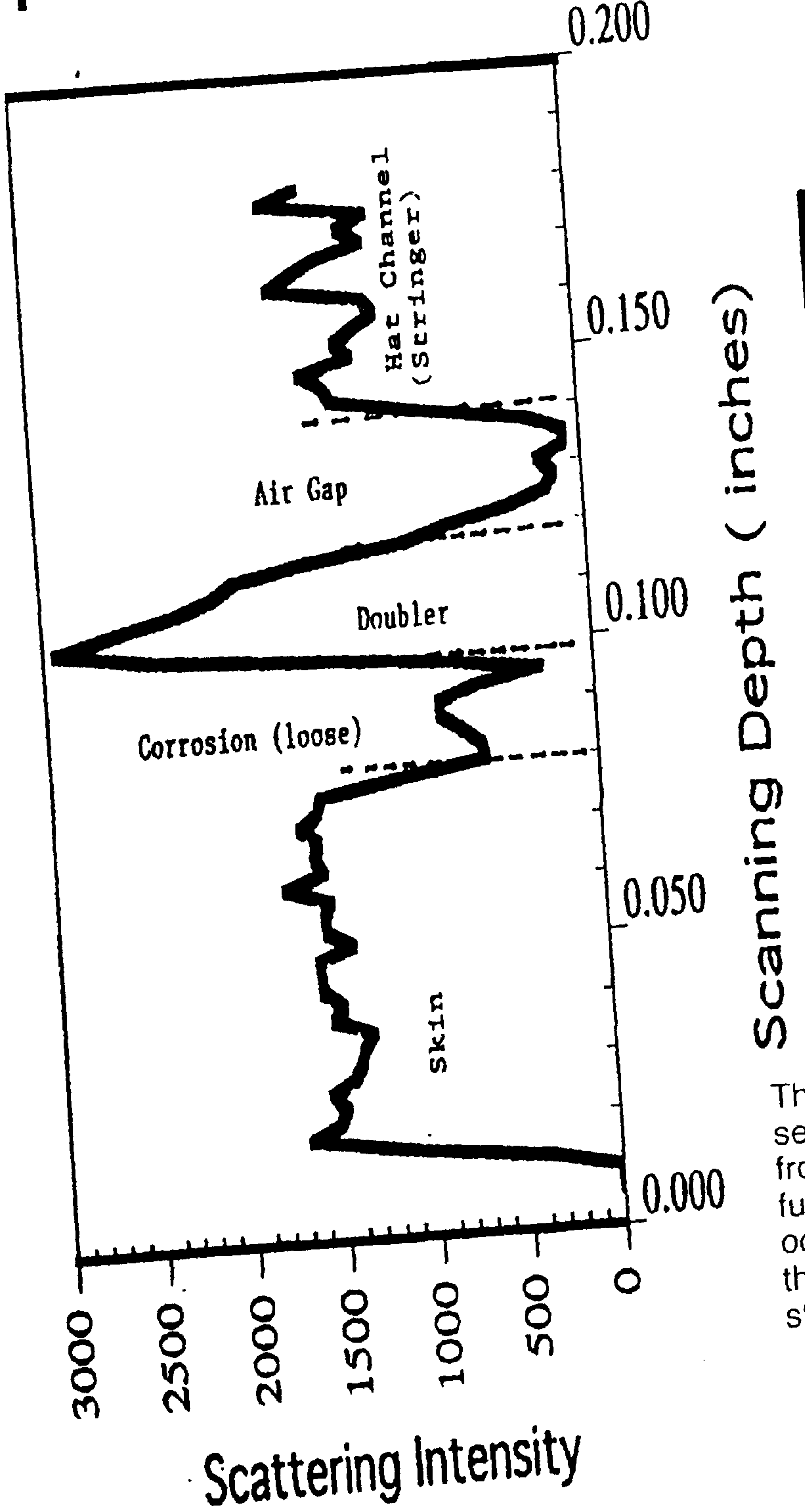
Depth Profiling Apparatus

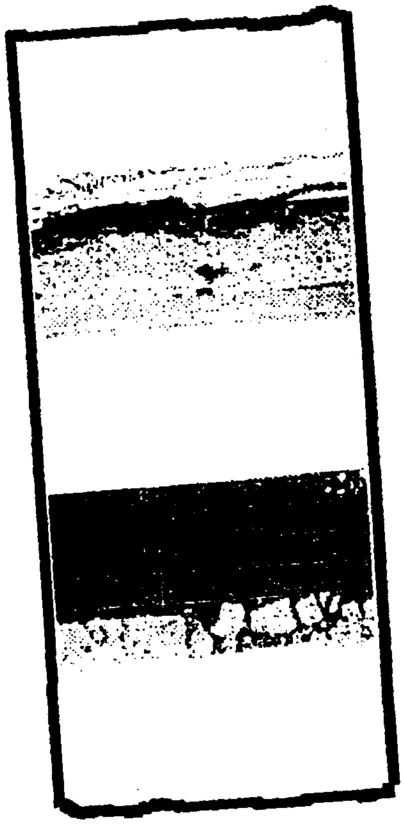


The depth profiling camera consists of four sets of apertures. The first two sets form the beam into a pencil with a narrow rectangular cross-section. The second two sets select a limited thickness region from which backscattered photons reach the detector. The intersection of the incident and backscattered beam paths form a scattering zone or focal region. Sweeping this region through the material to be examined allows visualization of the electron density of the material along the path. In depth profiling, the path is normal to the surface and the result is similar to drilling and examining a core section taken at that point.

The scattering zone is nearly Gaussian in the depth direction with a "standard deviation" size parameter of 0.0013 inches.
Limiting (10% MTF) resolution is 10 lp/mm.

epth Profiling vs. Core Sectioning





The scan on the left and the core section on the right were both taken from the same area on a corroded fuselage. Some displacements occurred as a result of drilling. Note the exfoliative corrosion of the stringer (at the top of the picture).

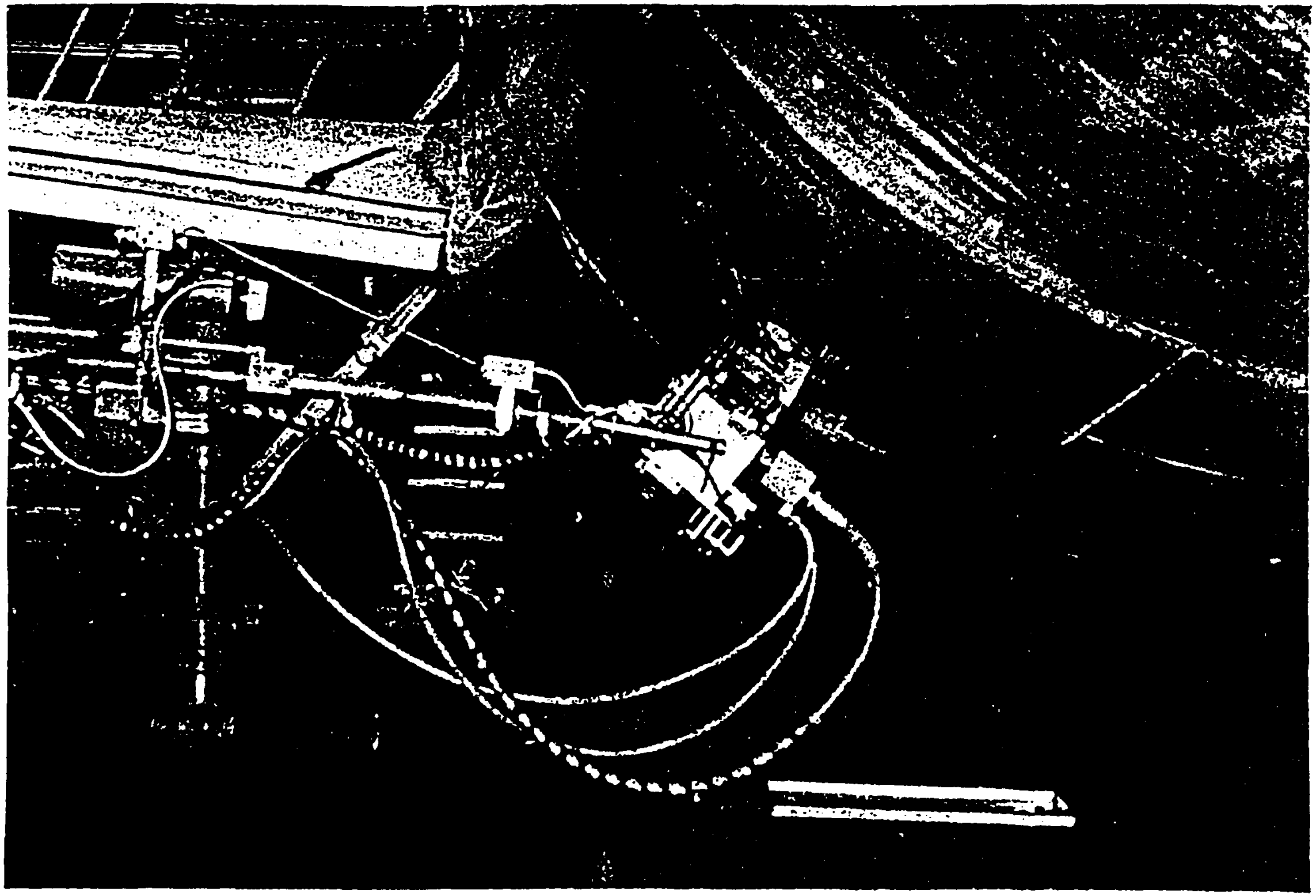
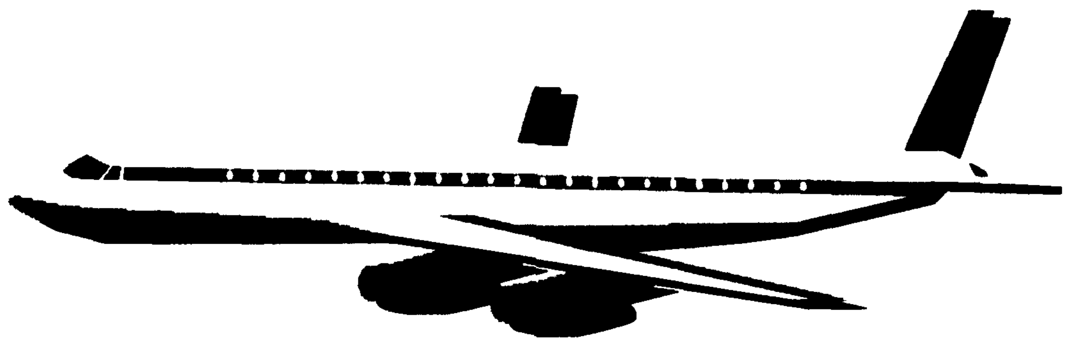


Fig. 4 X-Ray BDP Scan in place underneath an aircraft for scanning the belly section.

Date: 4/8/94

Future Technology Transfer/Assessment Plans at AANC

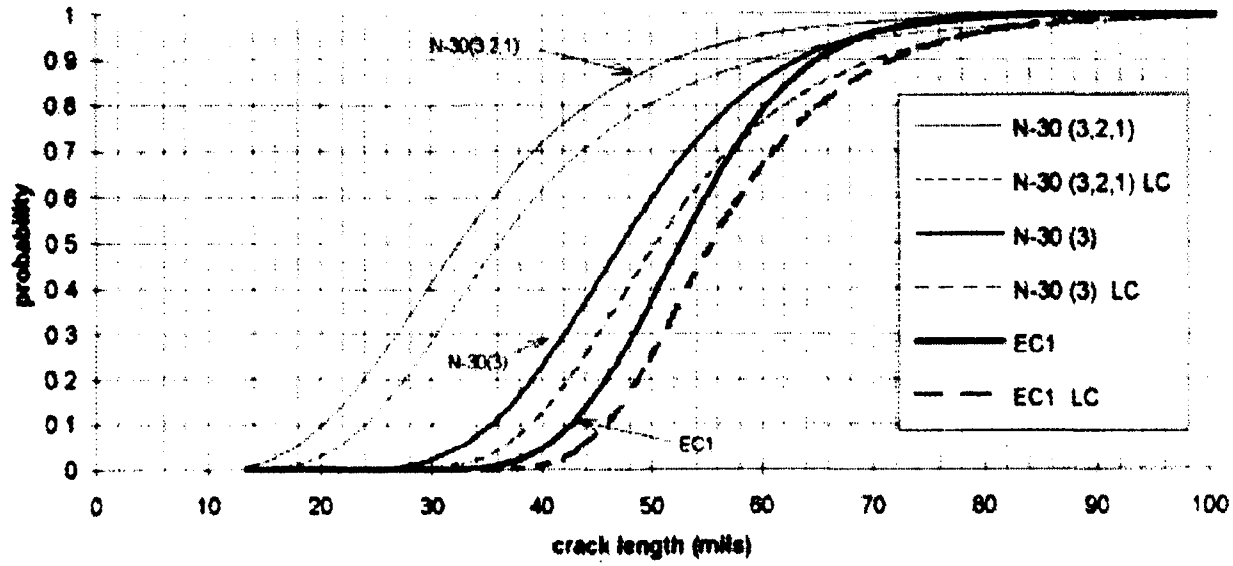


P. L. Walter
Sandia National Laboratories

Follow-Up Activities to C-Scan Imaging Scanner Evaluation

- Detailed Evaluation Select Scanner(s)?
- Beta-Site Testing?
- OEM/Airline Feedback Required

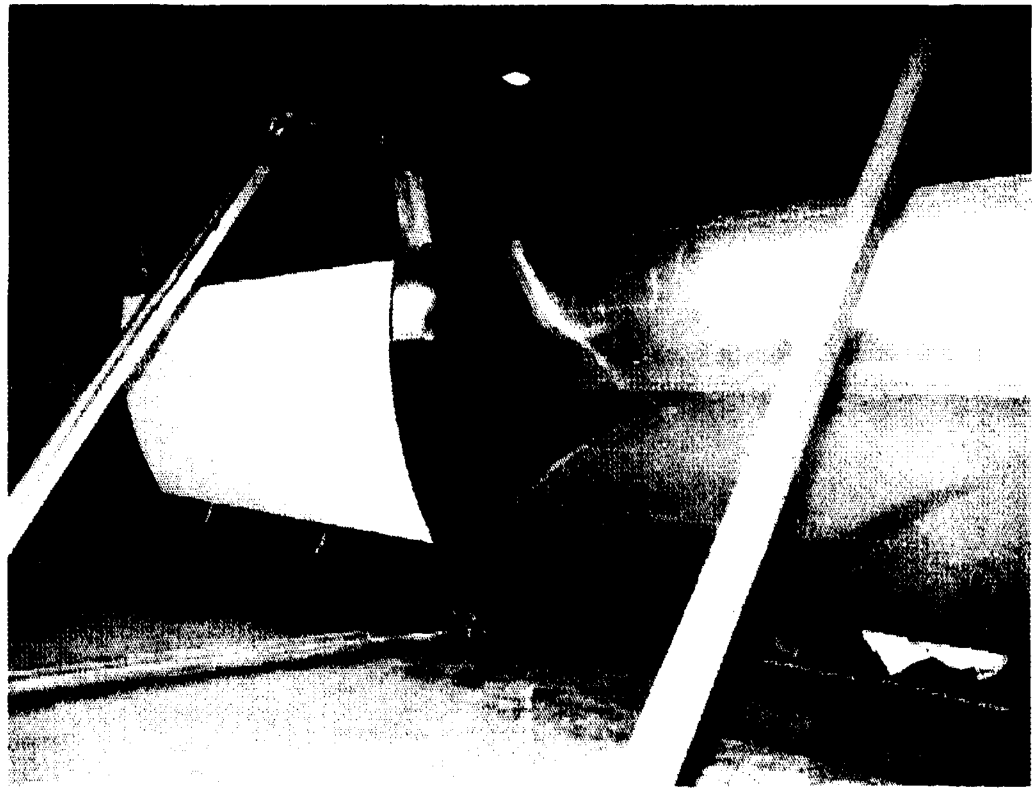
Ongoing Assessment of Rivet Crack Inspection Capabilities



- Commercially Available Instrumentation
- Emerging Instrumentation (FAA Research/Industry)
- Assess Procedure Changes

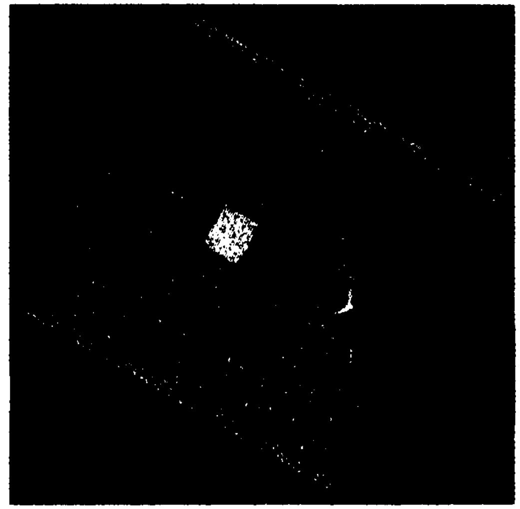
Design/Build 2nd, 3rd Layer Crack Specimens

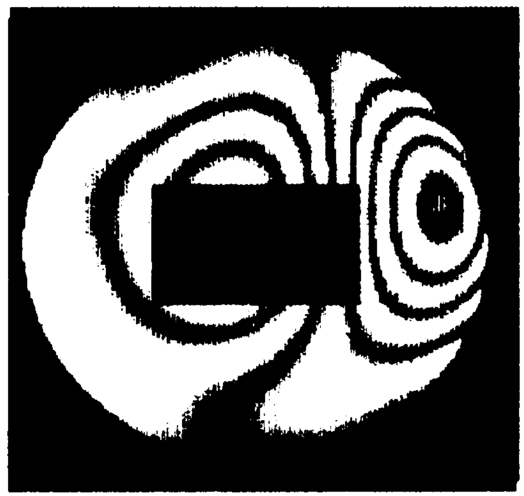
- Statistical Array Required for Technology Assessment
- Coordinate Specimens Design with OEMs



Perform Beta-Site Testing On NMSU Shearography Code

- Feedback required to move to Industry
- Allows NMSU to move to quantitative strain





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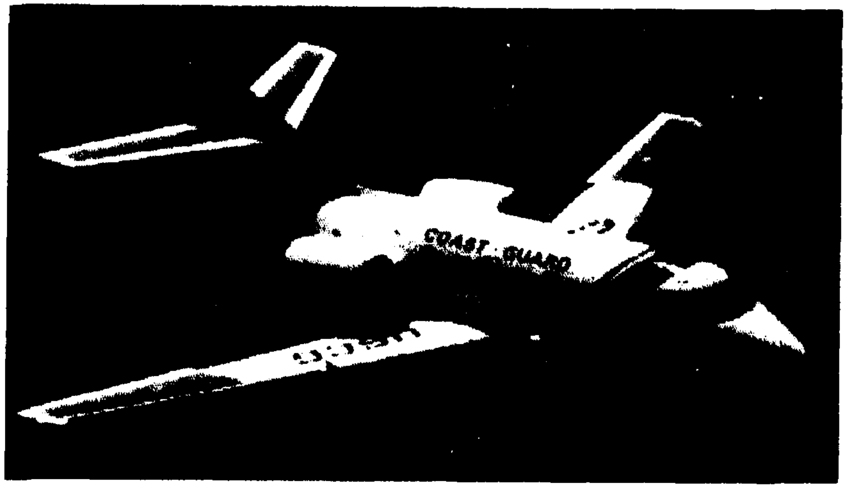
Cooperate With Other Government Agencies on Technology Exchange

- Work For Others Agreement with US Coast Guard
- Contribute Falcon 200 Derivative Aircraft to Civilian Program
  - On call service/ maintenance support
  - All records/drawings



Development Testing

Continue to Assess Portable Lighting

- Integrate into Visual Experimentation Plan
- Implement Informal Field Trials
- Pass out Flashlights with Questionnaire at ATA/NDT Forum

Work With CASR to Demonstrate Their Technology Transfer Candidates

- Demo at next AANWG/TOGAA Meeting
  - Final Engineered Prototype
- Acquire Industry Feedback
  - Formal Validation
  - Cost Benefit Analysis

Date 4/8/94

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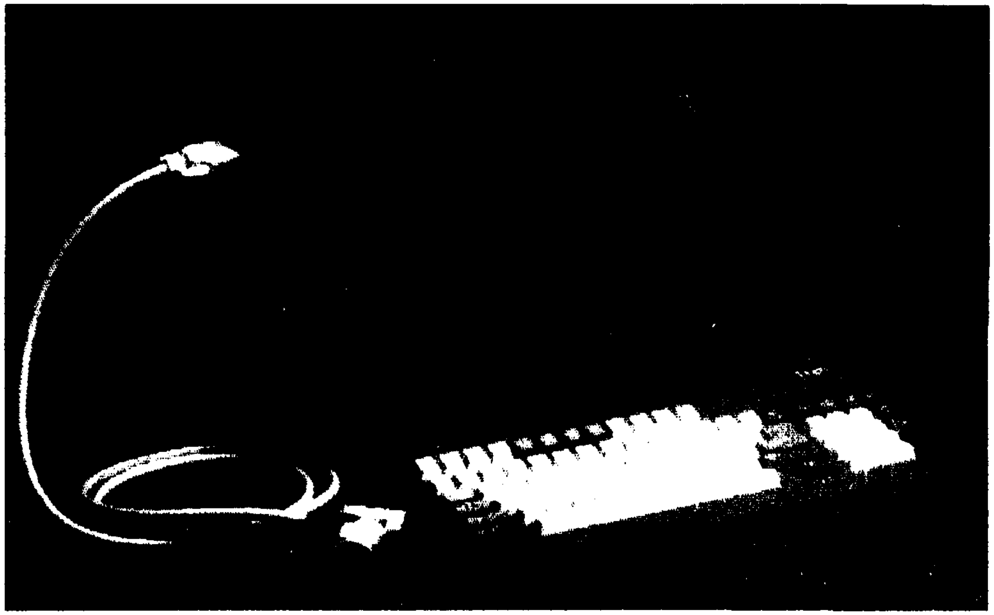
Continue to Work with Commercial Industry Northrop B-2 Division



Low Frequency Eddy Current Array

Development Testing

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Northrop B2 Division - LFECA

Northrop LFECA Commercialization Plans

1. Demonstrate LFECA to OEMs, users, government agencies.
2. Optimize probe effectiveness for focused applications.
3. Solicit OEM approval for application. Use FAA/AANC NDI Validation Center reliability study and airline feedback as basis.
4. Generate video to include POD curves from FAA/AANC NDI Validation Center.
5. Continue development of capabilities for corrosion detection, automation, image enhancement, linear array, and improved sensitivity.
6. Request expanded role of FAA/AANC NDI Validation Center in assessment of 2nd layer crack detection, thick skin POD, multi-layer (>2 layers) evaluation, and training signals.

"We support this Center because it provides us with an unbiased test center for evaluation of our equipment. This center is part of our continuous process improvement for LFECA."

Receiving USAF funding under contract CUFS. Northrop provided 100K$ IRAD funding after visit to FAA/AANC NDI Validation Center.

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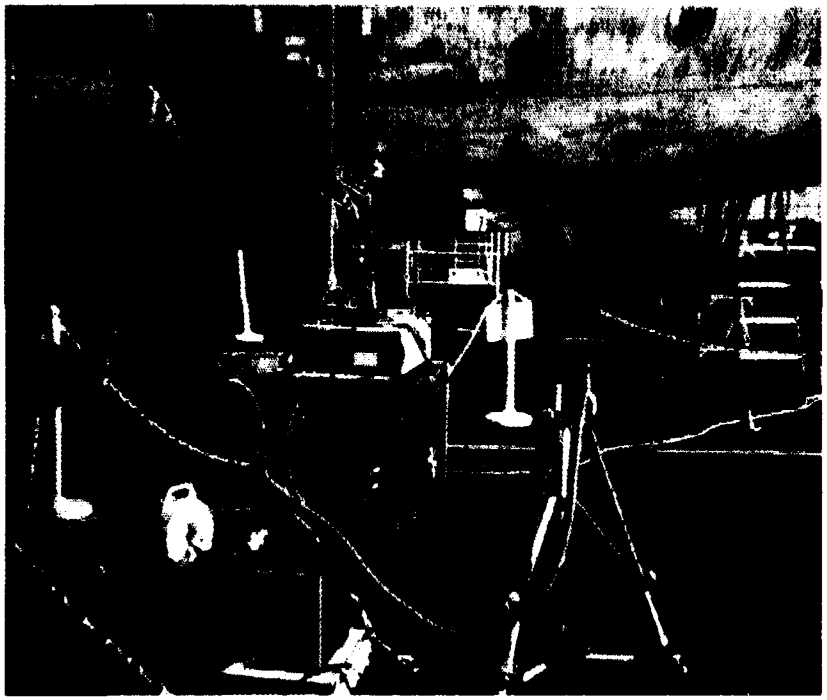
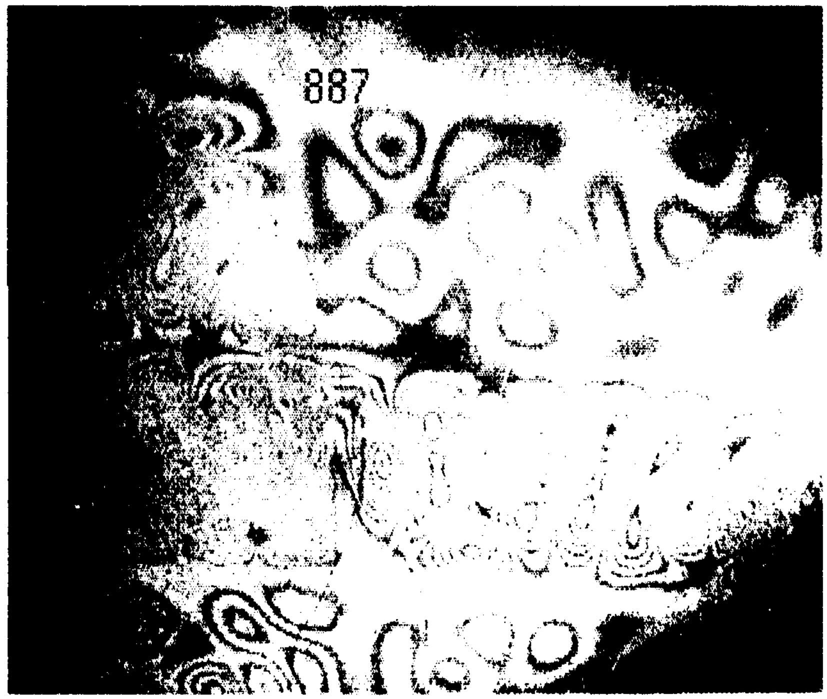
Continue to Work with Commercial Industry Holographics Inc.

Holographics Inc.
September 1993



Laser, Shaker and Control System Deployed on 737 Aircraft



Holograph of Debonded Tear Strap

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Holographics Inc. - Holography/Laser Doppler

Company/Technology Background

1. Founded 1982 to develop pulsed holographic lasers.

2. Late 80's developed interest in applying pulsed laser holographics equipment to perform NDT on in-service passenger aircraft fuselages.

3. Holographic based inspection process detects faults such as cracking in frames, stringers, clips, as well as corrosion and disbonds and uses a portable microprocessor controlled system while inspecting areas up to 6 feet in diameter.

4. Company is also researching a Doppler based laser system with remote acoustic excitation for application to metal and composite bond inspection.

5. Holographics Inc. will have spent 7 weeks at the FAA/AANC NDI Validation Center in the September 1993 - April 1994 time period acquiring knowledge, experience, and test data to provide a foundation for interfacing with the FAA and OEMs in requesting inspection certification.

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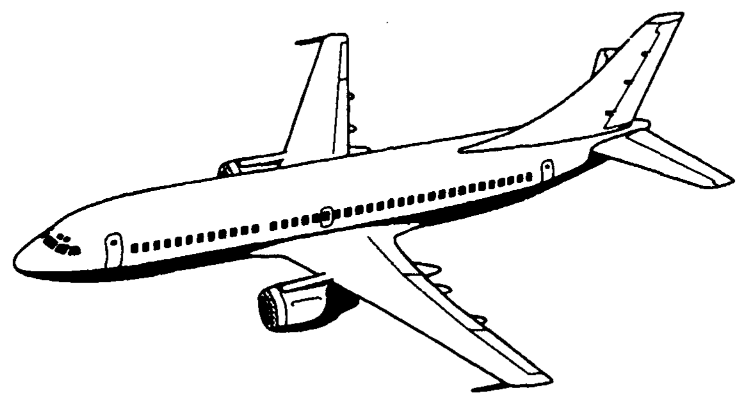
Date: 4/1/94

Eddy Current Inspection Reliability Experiment (ECIRE)



Floyd W. Spencer
AANC

PROGRAM SUPPORT: *Science Applications International Corp.*
AEA Technology

Development Testing

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Eddy Current Inspection Reliability Experiment (ECIRE)

The objectives of this project were to assess the reliability of field inspections of aircraft lap splices using high-frequency eddy current NDI procedures and to identify key elements that impact the reliability.

Eddy Current Inspection Reliability Experiment

Presentation Overview

- Background
  - Test Specimens & Crack Characteristics
  - Design Factors
  - Facilities Visited
- Analysis of Data
  - Probability of Detection (PoD)
  - Relative Operating Characteristics (ROC)
- Summary
  - Data
  - Observations

ECIRE - Approach

- Task simulation - Lap Splice Inspection
- Use facility personnel, equipment, and procedures
- Task performed in realistic environment
  - Noise
  - Light
  - Distractions

Date: 3/31/94

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ECIRE

- Simulated Lap Splice Inspection
- Two monitors
- Two types of test specimens

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Development Testing

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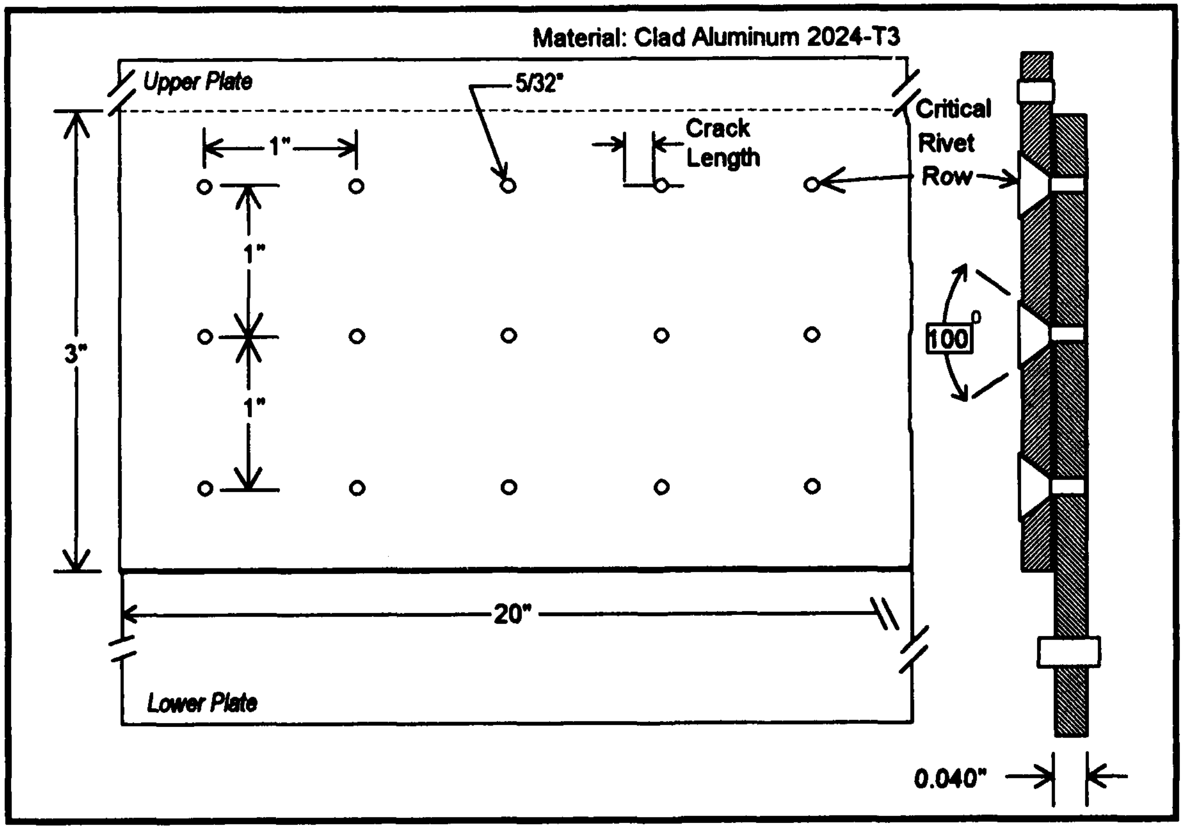
Skin Panels

- Material and dimensions to Boeing specifications
- 20 inch by 20 inch
- Skins only - fatigued then configured

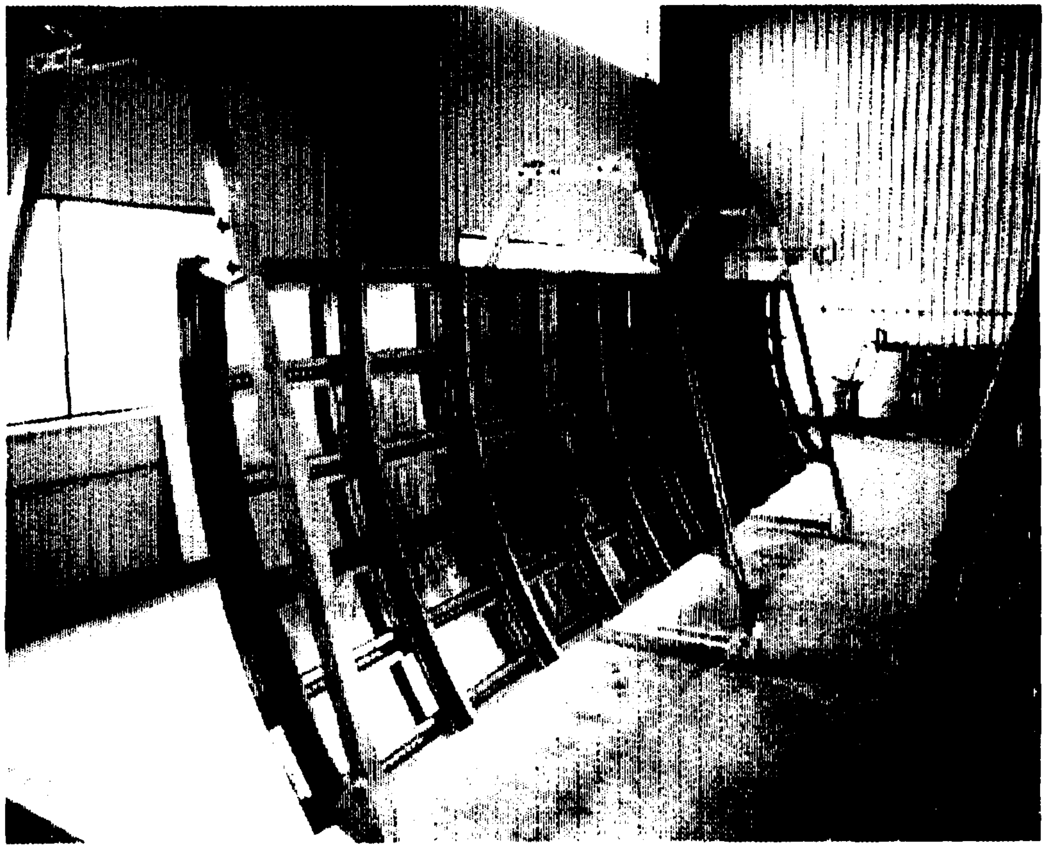


Development Testing

Sandia National Laboratories

Aircraft Panels (Foster-Miller)

- Materials and dimensions to Boeing specifications
- Ribs and stringers in place
- Fatigued as a structure
- 8 1/2 feet by 4 feet



Development Testing

Date 3/31/94

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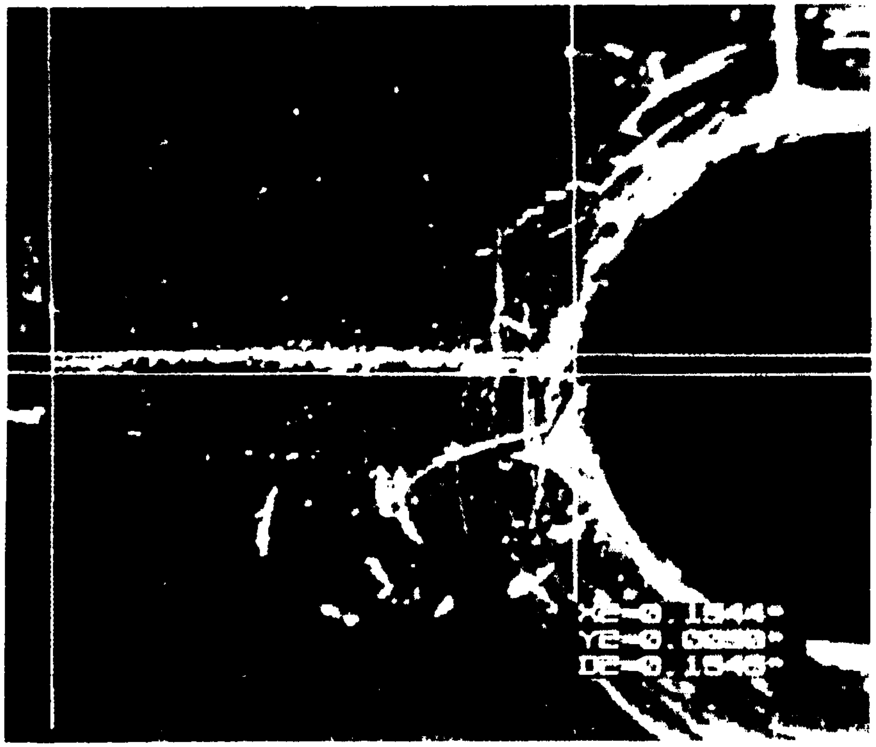
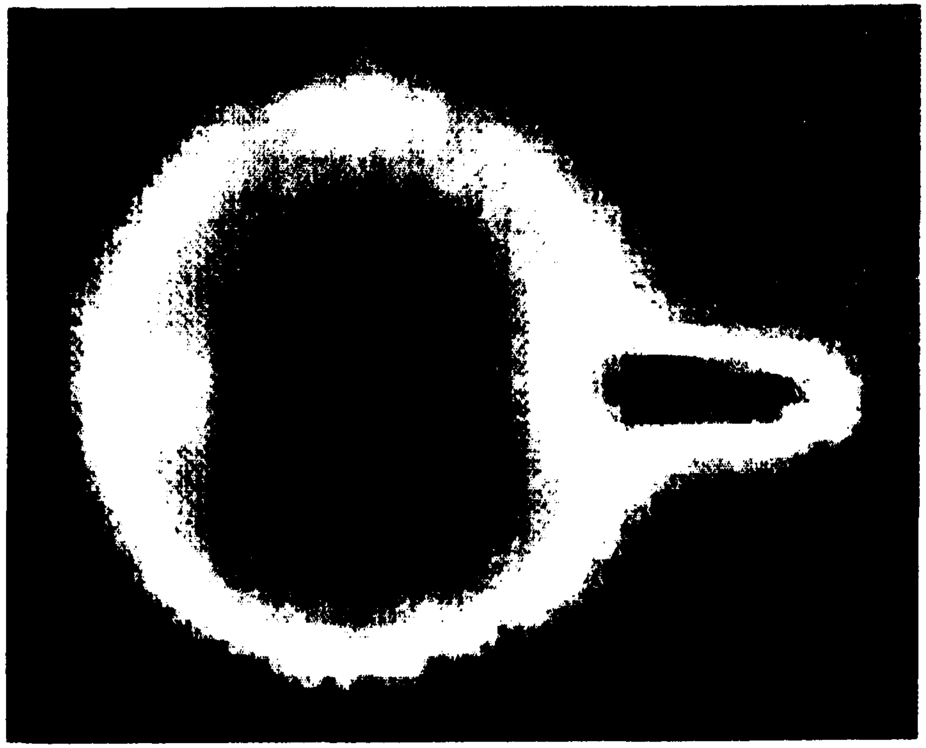
Crack Length Measurements

- Video based optical comparator



- Eddy current imaging



Development Testing

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Inspection Task Background

Following designed into experiment

- 924 inspection sites (rivet locations)
  - 720 rivets in skin panels
  - 204 rivets in aircraft panels
- 184 flawed sites
  - 122 sites in skin panels
  - 62 sites in aircraft panels
- 57 double flaws
  - 50 sites in skin panels
  - 7 sites in aircraft panels

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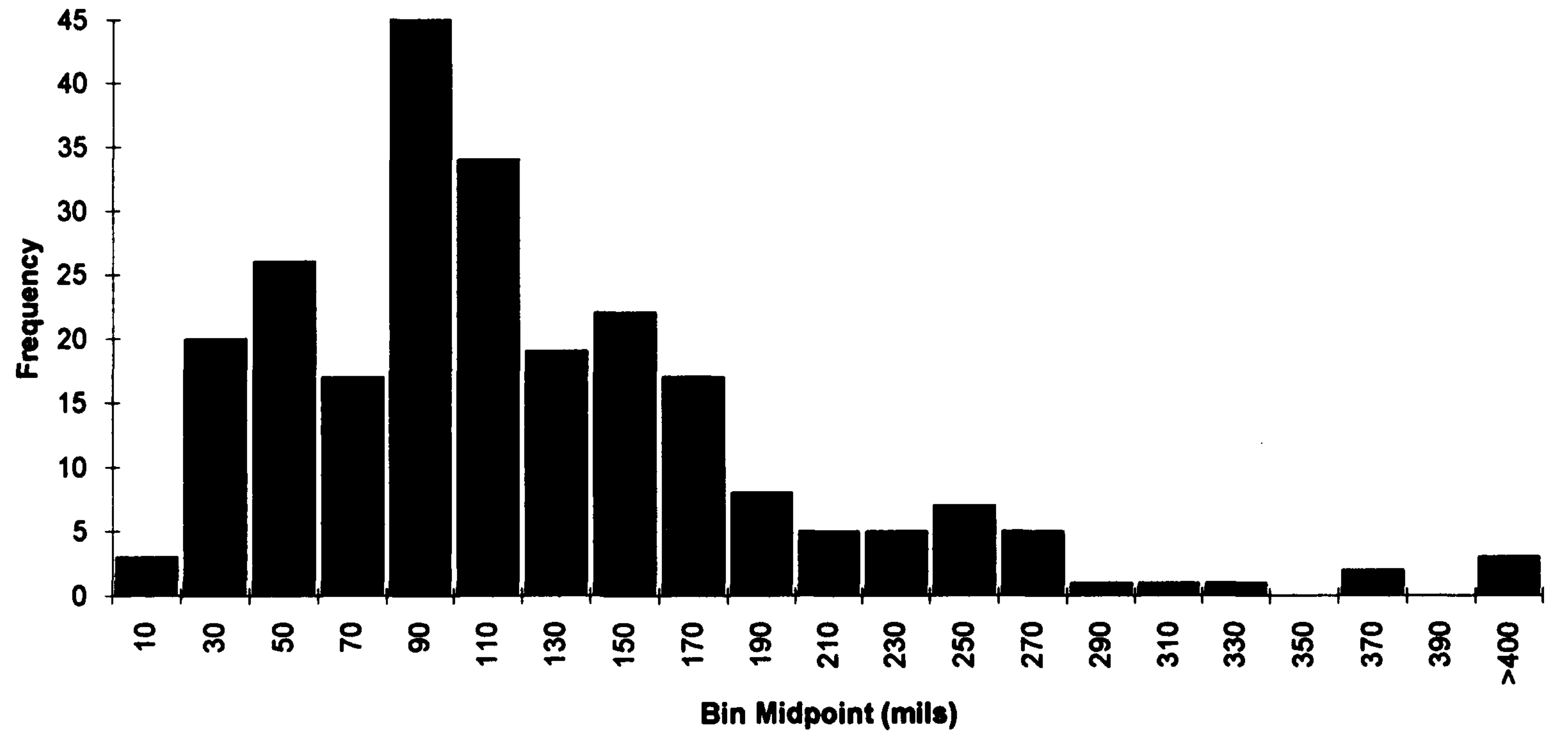
Distribution of Crack Lengths (241 total)



Development Testing

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Experiment Controlled Factors

- Test Specimens

  Test specimen type - skin and aircraft

  Crack length distribution - 14 mils to 812 mils

  Off-angle cracks - horizontal, 11°, 22°

- Laboratory Baseline

- Task Related

  Inspection surface - Painted vs. Unpainted

  Task accessibility - two levels

  Inspection time - ~ 4 hours

  Shift work - Inspections from all shifts

  Repeatability - Same inspector(s) repeats

Acquire Facility/Inspector background data

Site Visitation Schedule

American Airlines	✓ March 1 - 12
Dalfort Aviation	✓ March 29 -April 9
Aloha Airlines	✓ April 21 - 29
Tramco	✓ May 6 - 13
Alaska Airlines	✓ May 17 - 21
United Airlines	✓ June 9 - 24
Delta Airlines	✓ July 13 - 19
USAir	✓ July 22 - 28
Miami NDT	✓ August 9 - 13

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Eddy Current Inspection Reliability Experiment Sites

Development Testing

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Data Analysis

- Probability of Detection (PoD) Curves
  - Individual Inspections
  - Regression - style fits to study factor effects
- Relative Operating Characteristic (ROC) Curves
  - False calls incorporated into analysis
  - Requires elicitation of confidence values from inspector

PoD Curves

- **Probit fits**

$$\mathrm{PoD}(a) = \Phi(\alpha + \beta \cdot ln(a))$$
$$= \Phi\left(\frac{ln(a) - \mu}{\sigma}\right)$$

where Φ is Normal Distribution Function

- **Similar to Logistic Fits**

Laboratory Baseline

The objective is to characterize the reliability under the most favorable conditions with an extremely skilled set of personnel.

- Personnel allowed to select equipment
- Excellent working conditions
- Minimal time constraints

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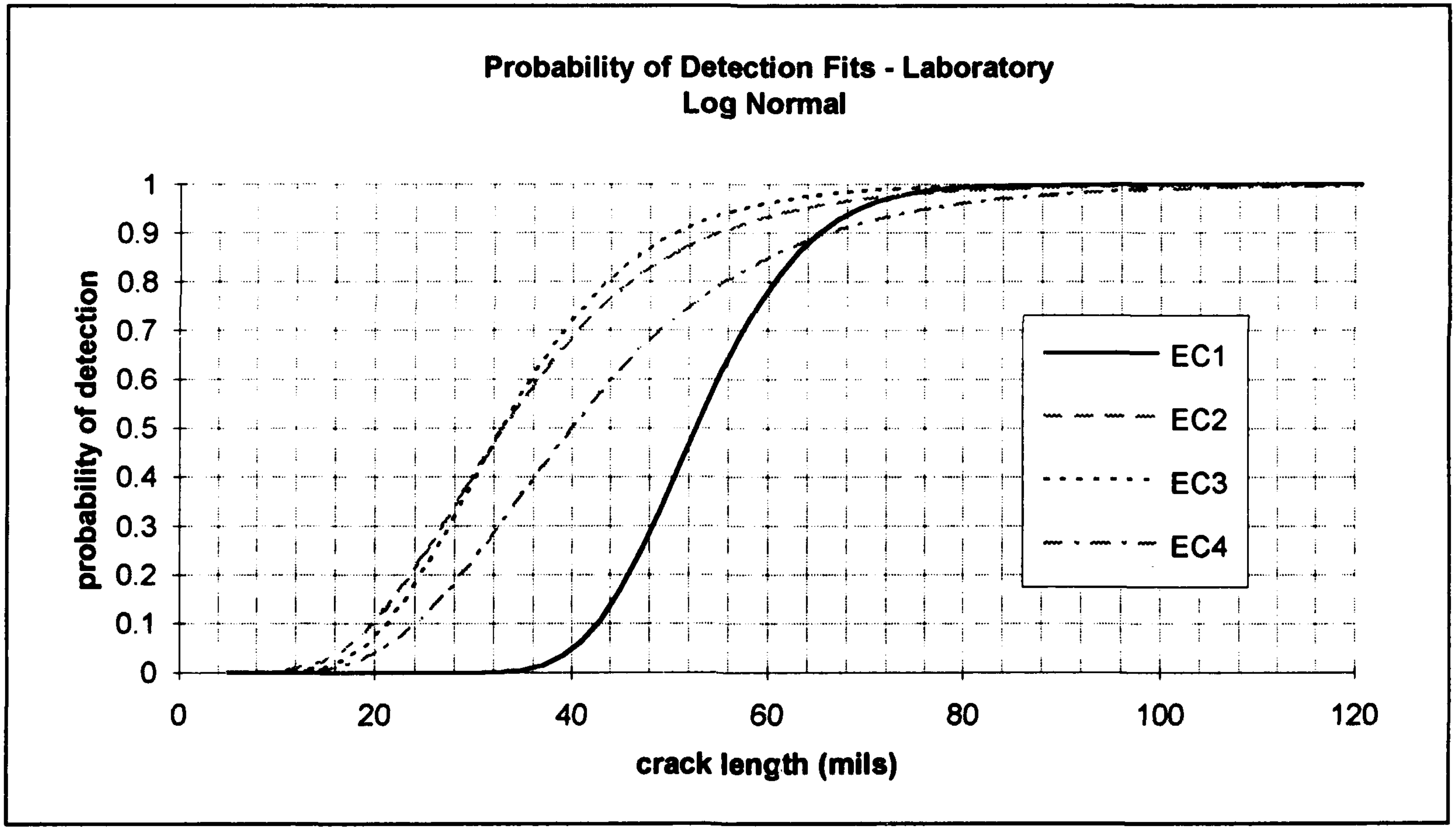
Laboratory Baseline

Background on Inspectors and Procedures - All used Rohmann Elotest B2.

Inspection	Qualifications	Procedure	False Call Rate (%)
EC1	NDT Level III, Supervisor and Examiner - >25 years aircraft experience	Sliding probe - 16 kHz	.9
EC2	NDT Level III, ASNT Level III - >25 years in NDT training	Template - 20 kHz	.3
EC3	ASNT Level III - >18 years in NDT training & development	Template - 30 kHz	.3
EC4	ASNT Level II - 13 years experience in NDT inspection and development	Template - 30 kHz	.9

Date: 4/1/94

Laboratory PoD Curves



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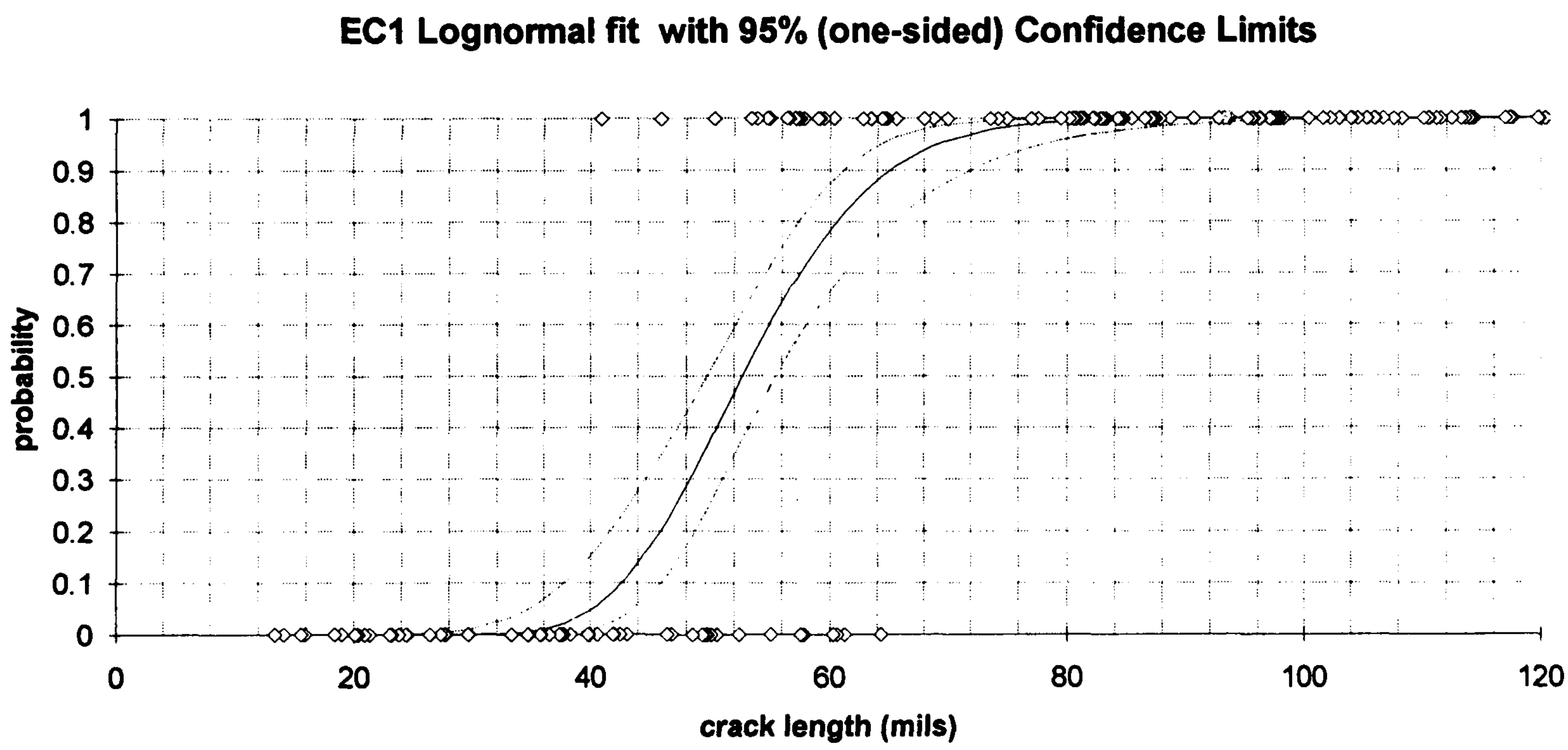
Laboratory PoD w/ Confidence Limits



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PoD Curves with Background Miss Rate

- PoD does not achieve 1 - asymptote of (1-C), where C is a background miss rate
- Observed behaviors suggesting model
  - Missed inspection areas when moving equipment
  - Distractions from colleagues and other activities
  - Intermittent Equipment problems
  - Reliance on audible alarm in presence of increasing ambient noise
- Overall Background Miss Rate (data fit)

  C= .02

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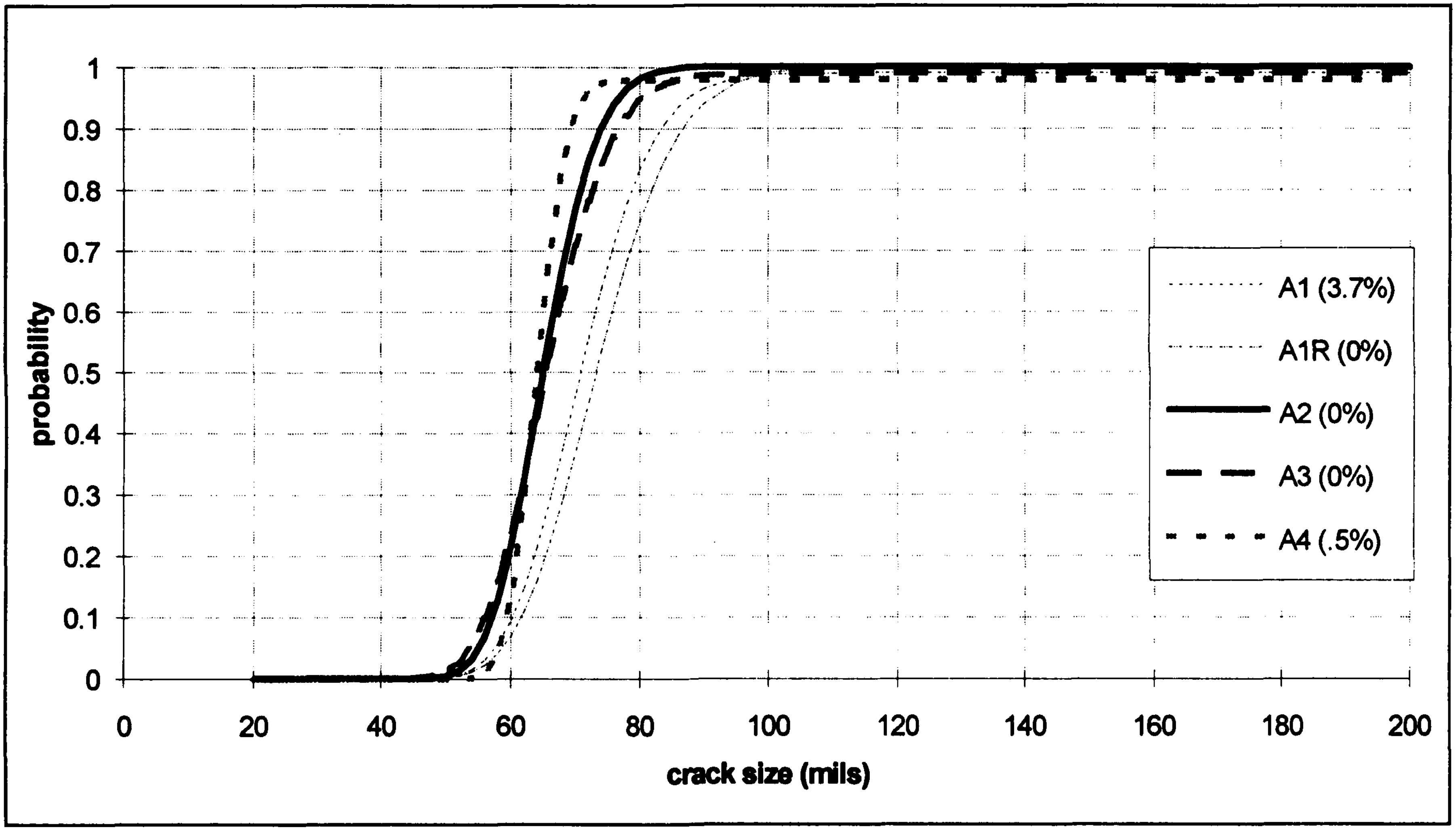
Facility A - PoD Curves



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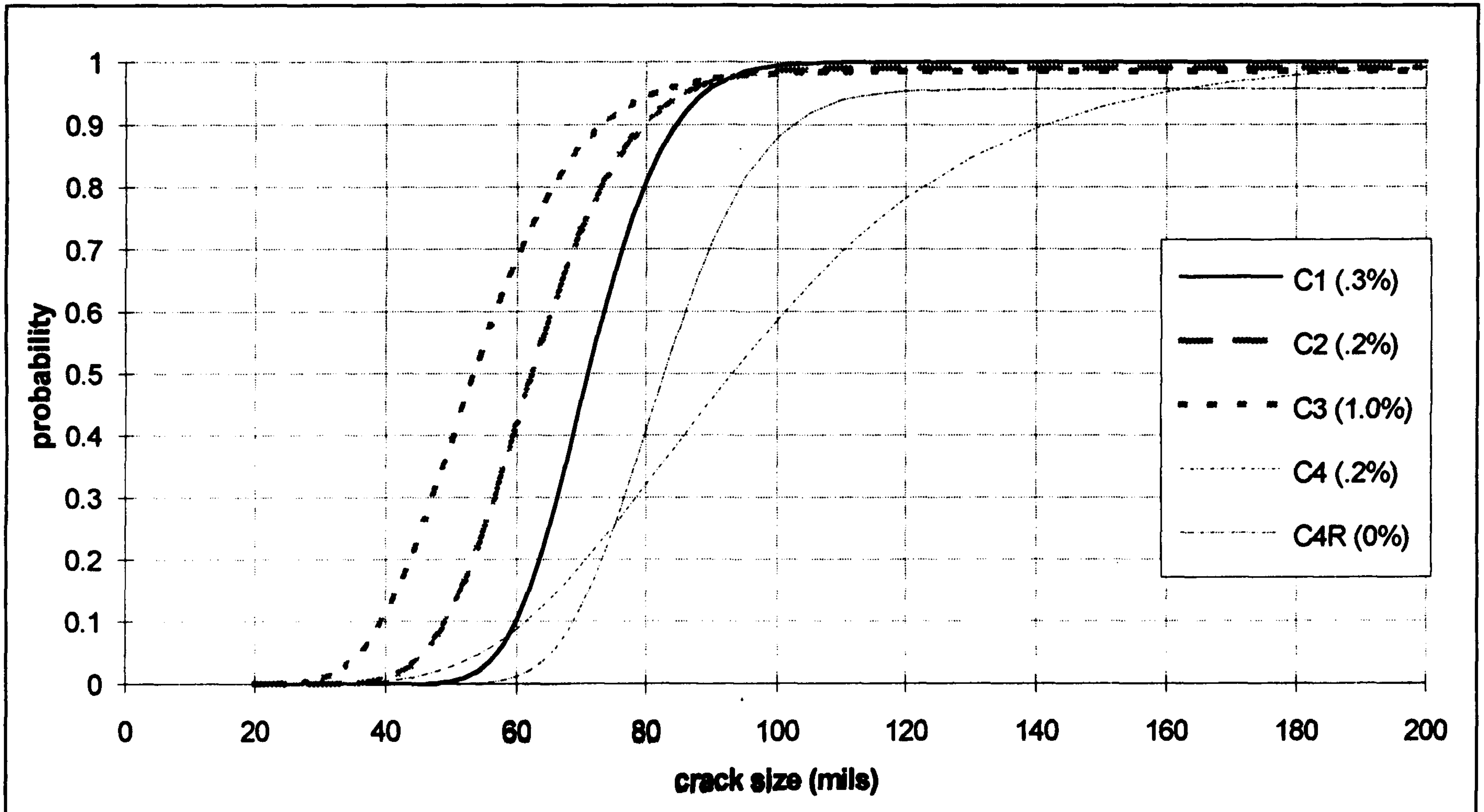
Facility C - PoD Curves



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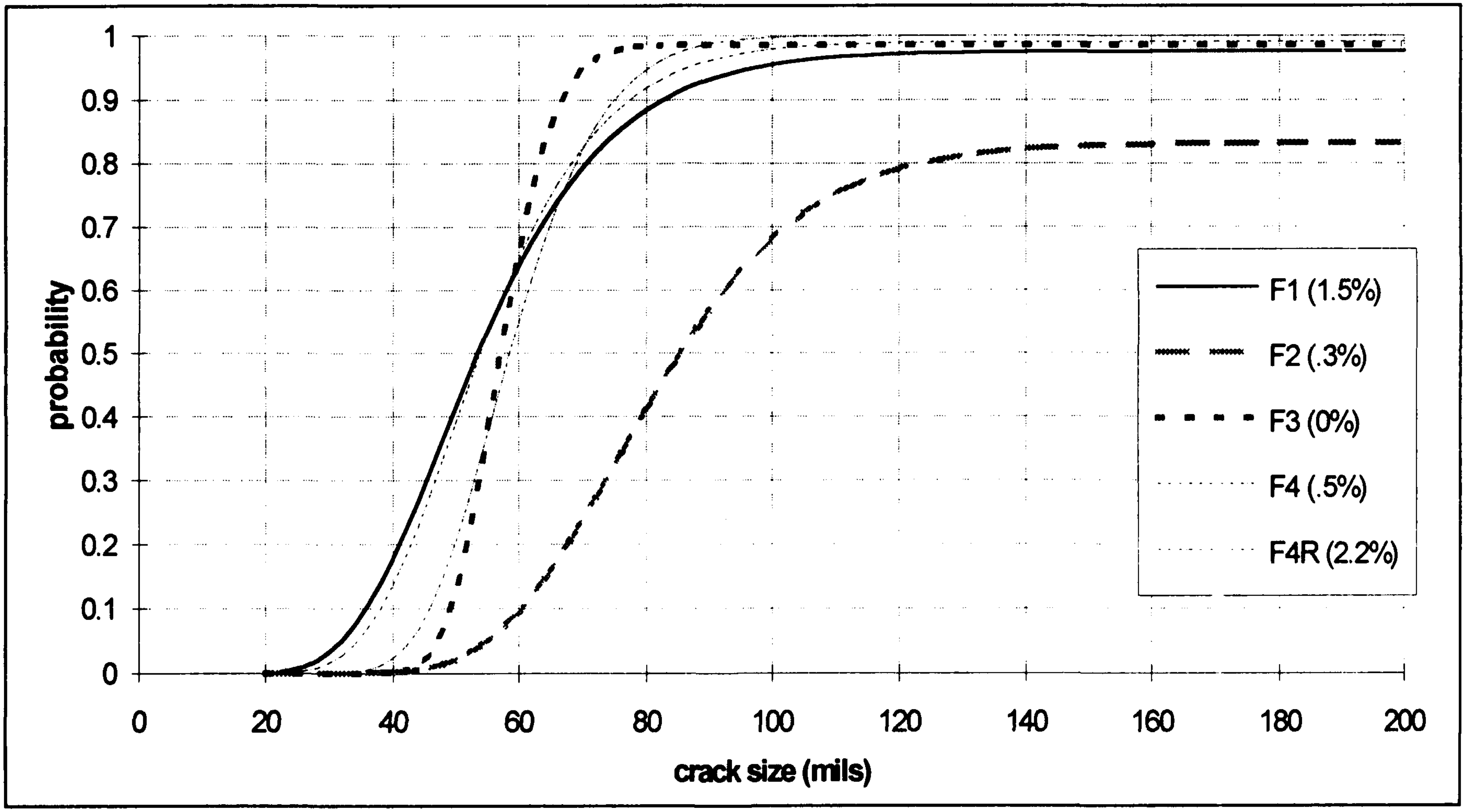
Facility F - PoD Curves



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Date: 4/1/94

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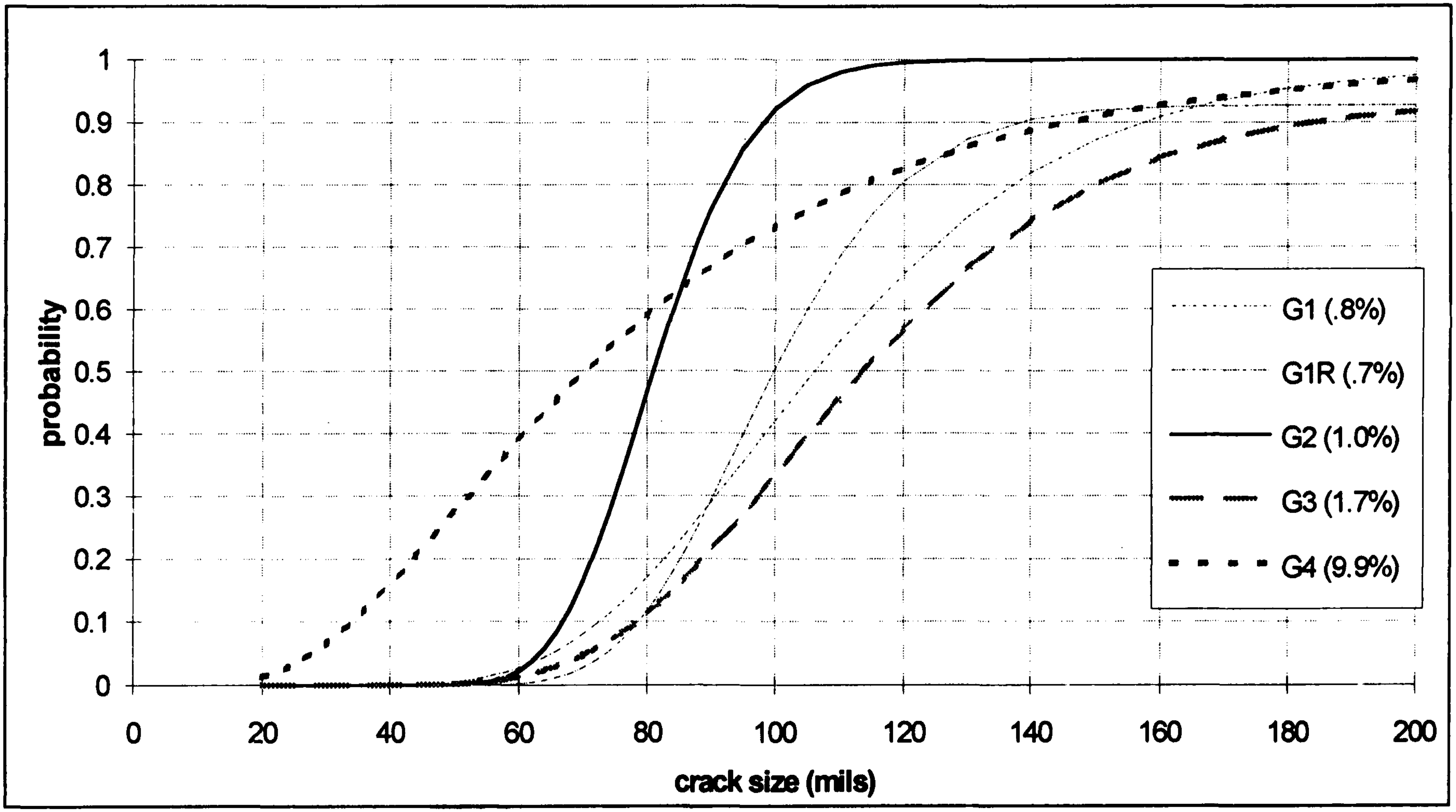
Facility G - PoD Curves



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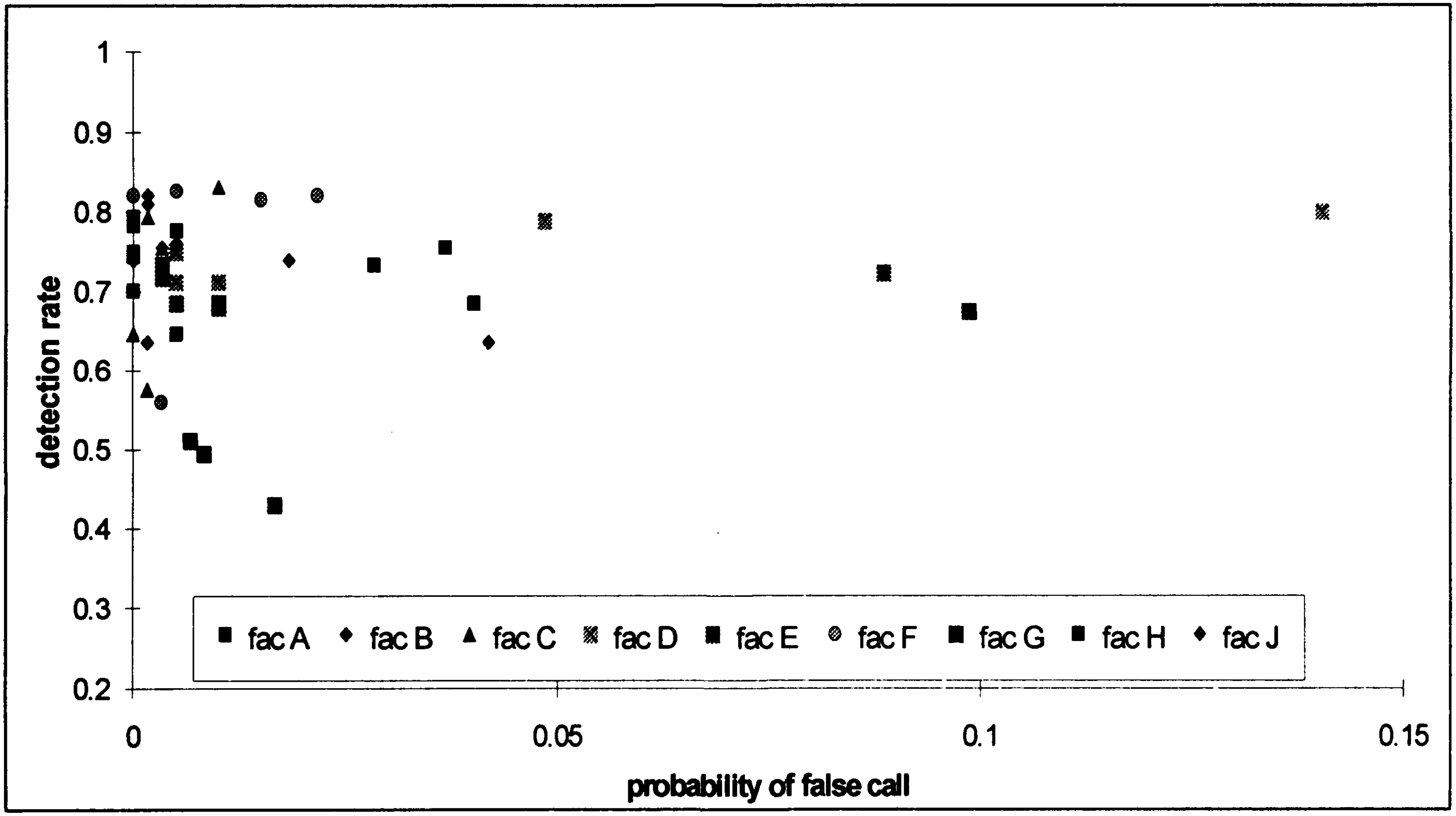
Overall Detection Rate *versus* False Call Rate



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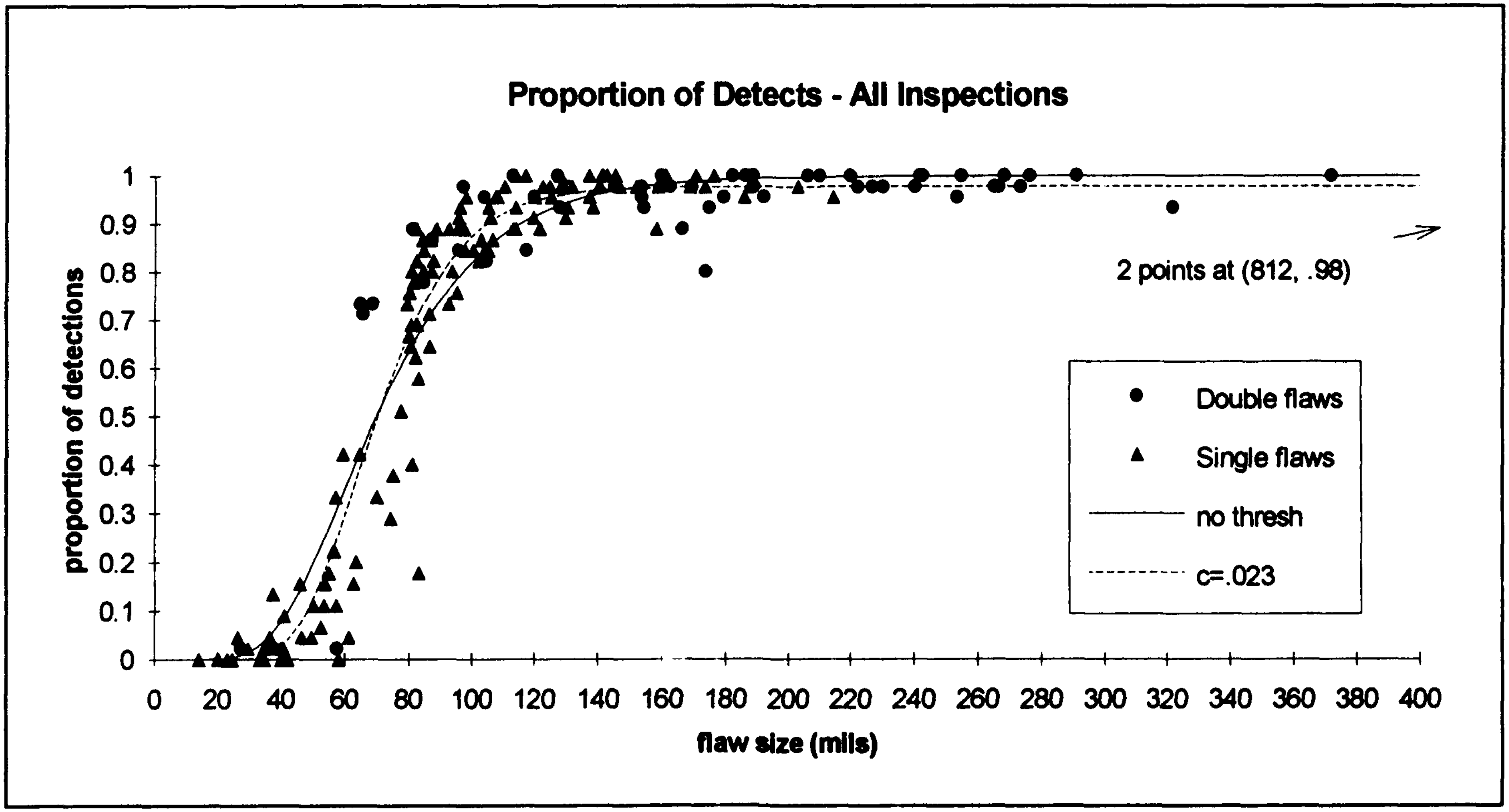
Average PoD


Proportion of Detects - All Inspections
proportion of detections
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400
flaw size (mils)
2 points at (812, .98)
Double flaws
Single flaws
no thresh
c=.023

Date: 4/1/94

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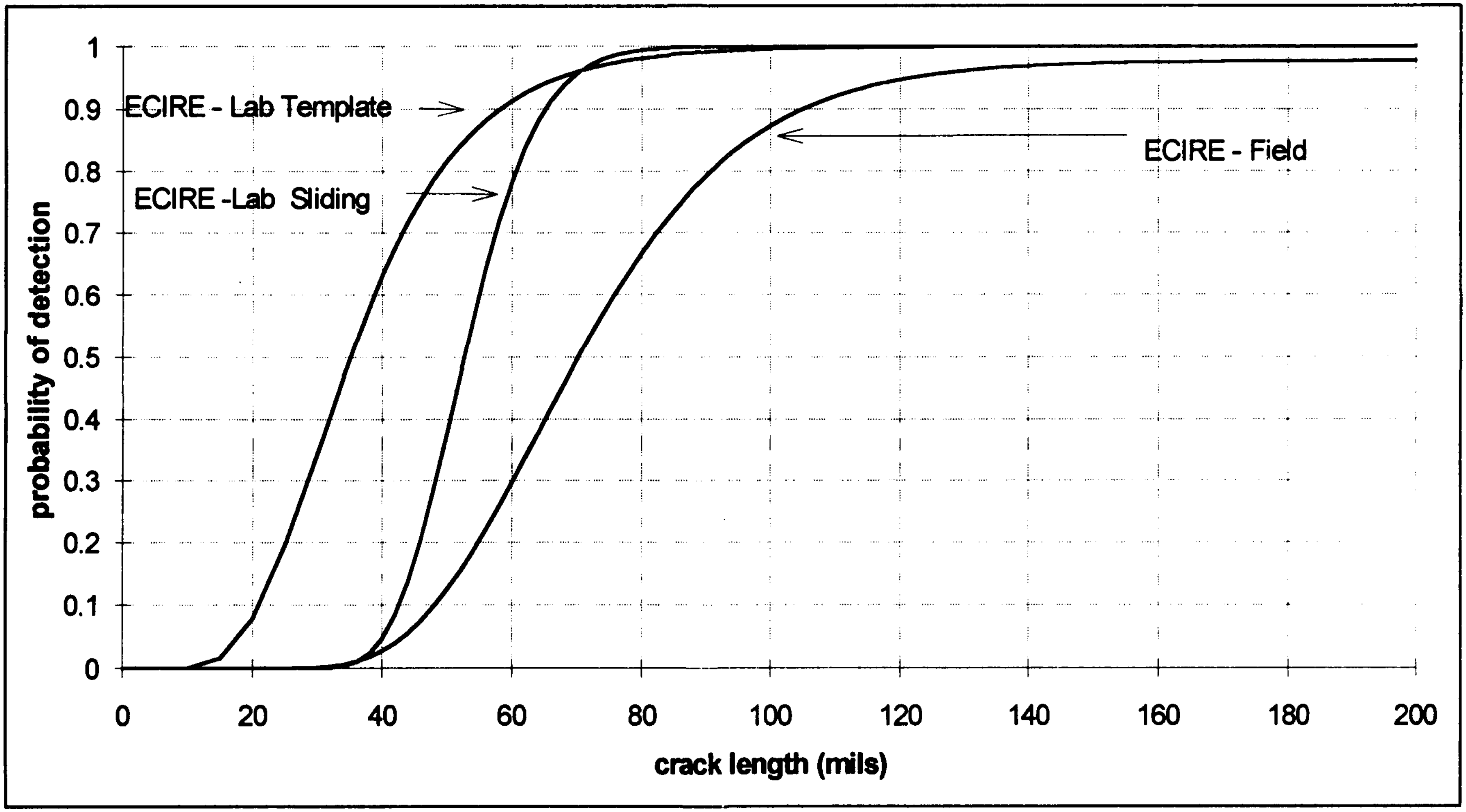
PoD Lab - Field Comparison



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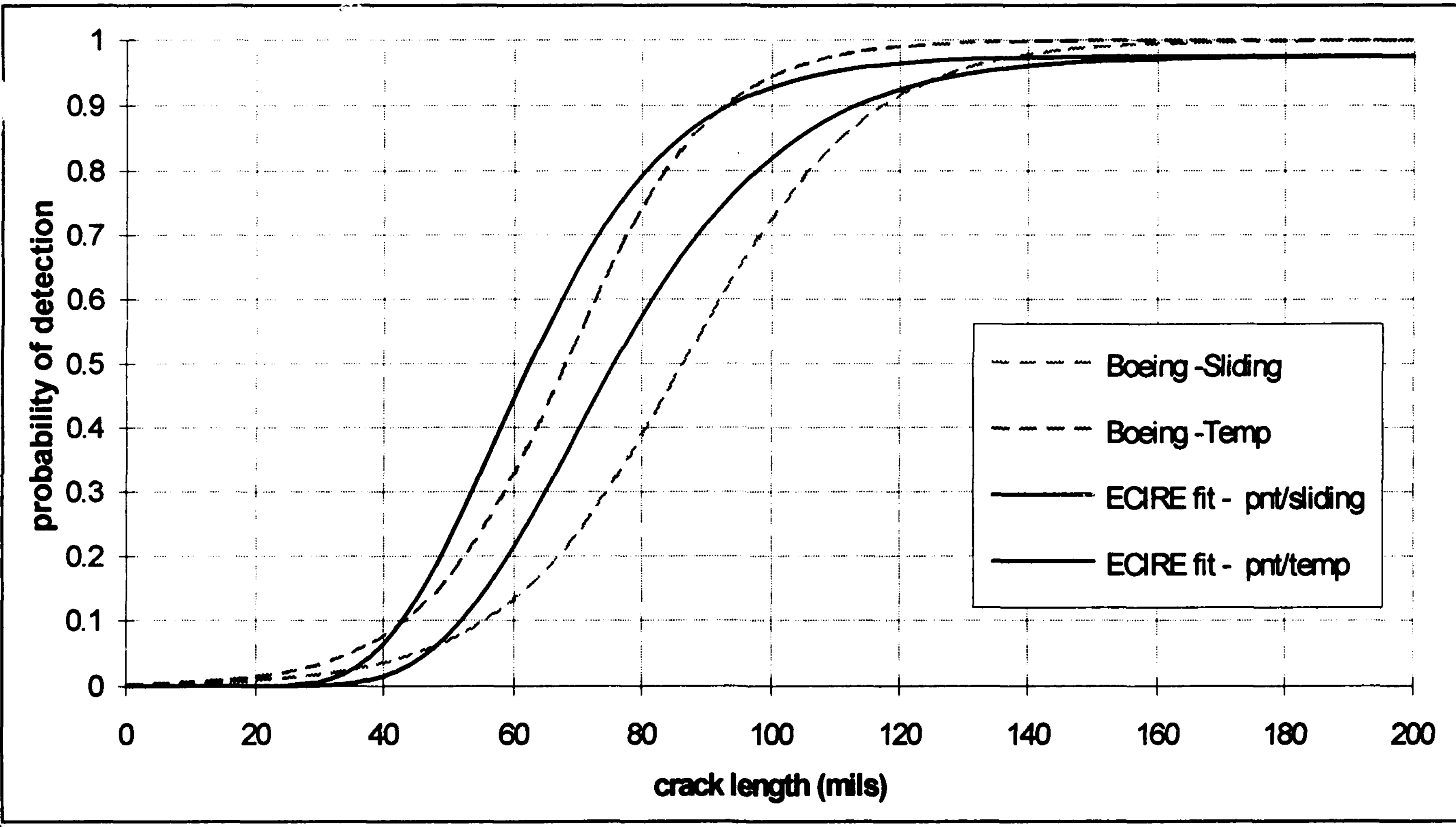
Comparison to Boeing Curves



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Development Testing

ECIRE - Findings

- For many inspections, PoD model with upper threshold produced substantial improvement in data fit
  - overall miss rate at about 2%
- Inspector-to-inspector account for major source of variation
- Facility differences are significant

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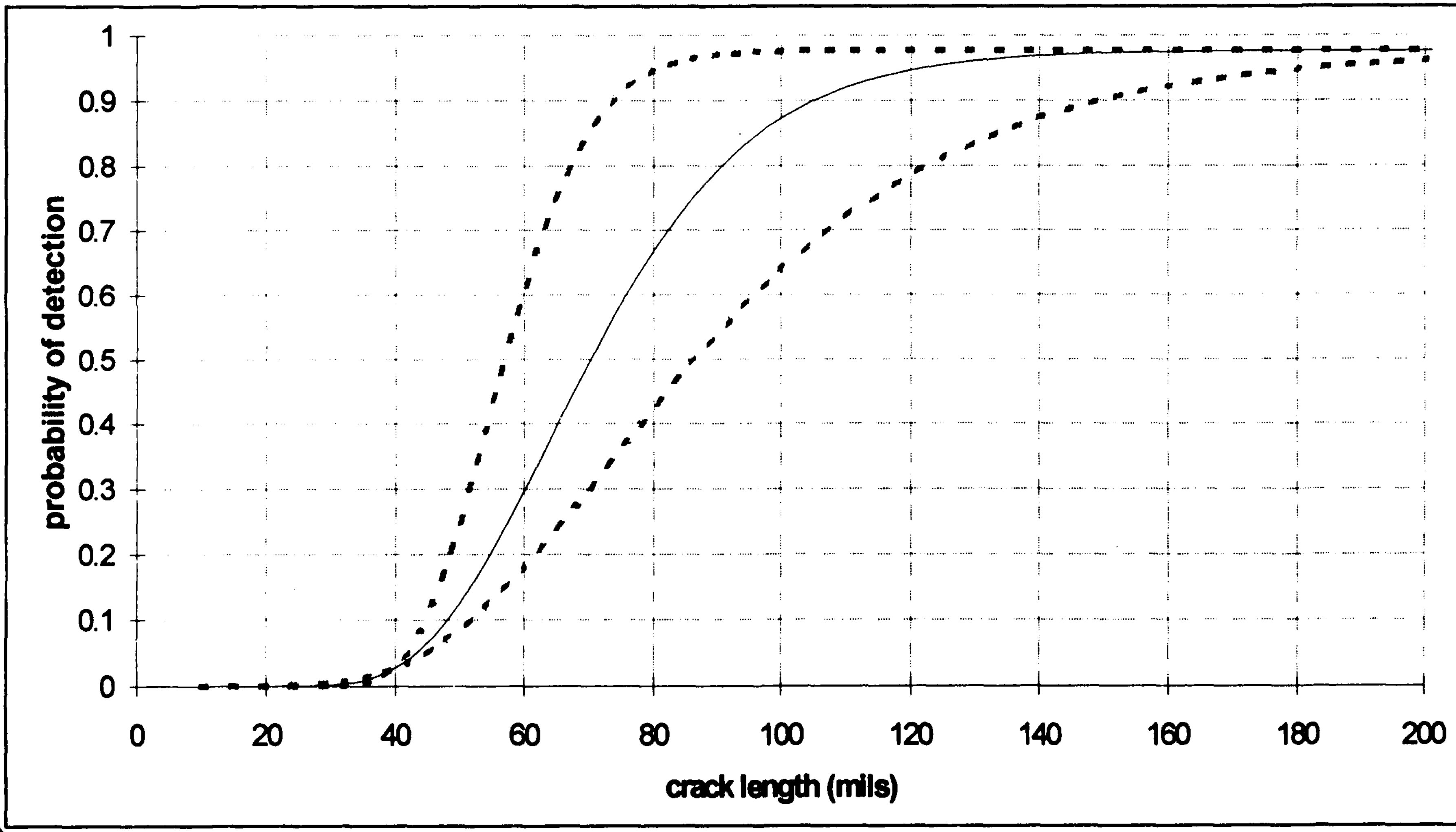
Inspector - to - Inspector Variation (95% Intervals)



Development Testing

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ECIRE - Factor Effects

Base case - bare surface, horizontal cracks, easy accessibility - average $a_{.90}$ = 90 mils

- Painted surface - add 25 mils
- Off-angle cracks (>11degs) - add 13 mils
- Mild accessibility problems - add 5 mils

ECIRE - Non Significant Factors

- Shifts
- Teams
- Time into Task

Observations

- Two facilities departed from Boeing procedures in using universal eddy current standard blocks. Performance was on opposite ends of scale. One facility did not use calibration standard.

- Team Implementation decreased inspection time by about 20%. No PoD effect.

Observations *(continued)*

- **Template verification of sliding probe**
  - No effect on probability of detection
  - Often overlooked by inspectors
  - Often done with less sensitive instrumentation than original
- **Inspectors with better performance did not always strictly adhere to Boeing procedure guidelines for making calls**
- **Equipment specific training often missing**
  - Less than optimal setups
  - Lack of use of full equipment capabilities
  - Management criticized for taking training and not doing adequate job of transferring the training

Improvements

- Procedure adherence / Optimization of procedures
- Better training on specific equipment

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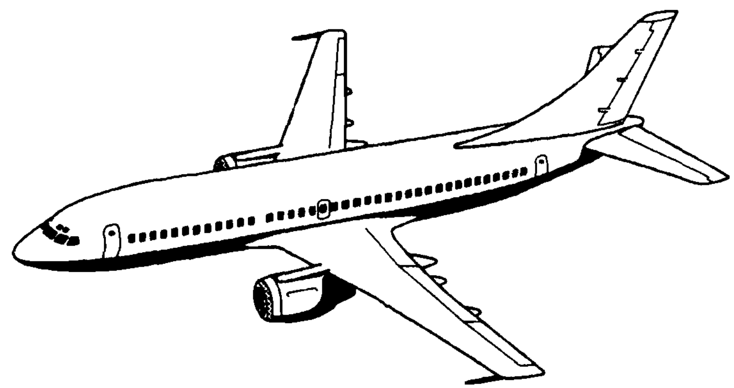
Date: 4/1/94

Visual Inspection Program



Floyd W. Spencer
AANC

Department 2757, Aging Aircraft Project

Development Testing

Motivation

- Visual Inspection is the dominant inspection process for aircraft maintenance (transport and commuter)
- Non-directed visual inspections are the primary source of identifying previously unknown damage

Visual Inspection Program

Goal:

Quantify reliability associated with visual inspection processes,

identify areas where processes can be improved, and

identify methods for enhancing the reliability of visual inspection processes

Visual Inspection Reliability Planning Group

- Sandia
  - Floyd Spencer
  - Craig Jones
- SAIC
  - Don Schurman
  - Mike Ashbaugh
- SUNY - Buffalo (OAM)
  - Colin Drury
- AEA Technology
  - Bob Murgatroyd
  - Ron Smith

Resources

- "Human Factors in Aviation Maintenance" (DOT/FAA/AM 91/16, 93/5, 93/15)
- "Visual Inspection for Aircraft" (Advisory Circular 43-XX)
- Aviation Conference Presentations addressing Visual Inspection
- Research literature in Human Factors arena
- Other FAA projects

Sandia National Laboratories

Date: 4/1/94

Visual Inspection Program Phases

1. Inspection Tasks Definition
2. Characterization of Flaws within Task Areas
3. Assessment of Current Visual Inspection Practices
4. Parametric Studies
5. Enhancement of Current Practices

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Development Testing

1. Inspection Tasks Definition

- Use of Boeing 737 in AANC Hangar
  - –synergetic with Baseline activities
  - –SBs, ADs, SSID
- Incorporate commuter when available
- Encompass range of visual "noise"
- Incorporate multiple decision criteria

Candidate Inspection Areas (gathered from field inspectors)

- Stringer 14 aft of BS 727
- Window beams
- Floor beams
- Keel beam
- Wheel wells

....

2. Characterization of Flaws within Task Areas

- Baseline activity for AANC 737 will provide initial characterization
- Introduction of flaws (or pseudo-flaws) in the event of “too few” flaws

3. Assessment of Current Visual Inspection Practices

- Multiple inspections
- Current Inspectors from maintenance and inspection facilities
- Nomimal conditions of the AANC hangar
  - Inspector feedback comparing to their 'normal' operating environment
- Report from this Phase

4. Parametric Studies

- Includes Enhanced Visual work
- Incorporate various factors, e.g.
  - lighting aids
  - light levels
  - task directivity
  - training tactics
- Use of InspectionTasks from phases 1 - 3

5. Enhancement of Current Practices

- Information gathered from phases 1 - 4 used to assess current practices
- Integrate with FAA/OAM Human Factors work
- Recommendations for enhancing the efficacy of visual inspection processes

Schedule

- Phase 1 and 2 completed in August '94
- Phase 3 activities will occur July - December '94
- Some Phase 4 activities will parallel Phase 3 and will be completed December '94
- Additional Phase 4 and Phase 5 activities in January to December '95

D Sight for corrosion detection in aircraft structures

Jerzy P. Komorowski, Ronald W. Gould,
Krishnakumar Shankar, Anton Marincak

Institute for Aerospace Research
National Research Council Canada

Omer Hageniers, Frank Karpala,
Don Clarke, Roger Reynolds

Diffracto Ltd.

NRC·CNRC

DIFFRACTO

D Sight for corrosion detection in aircraft structures

Sponsors:

Federal Aviation Administration

Transport Canada

National Research Council Canada

Diffracto Ltd.

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DIFFRACTO

3836 KEW DR., WIN ITARIO N8T 3B7

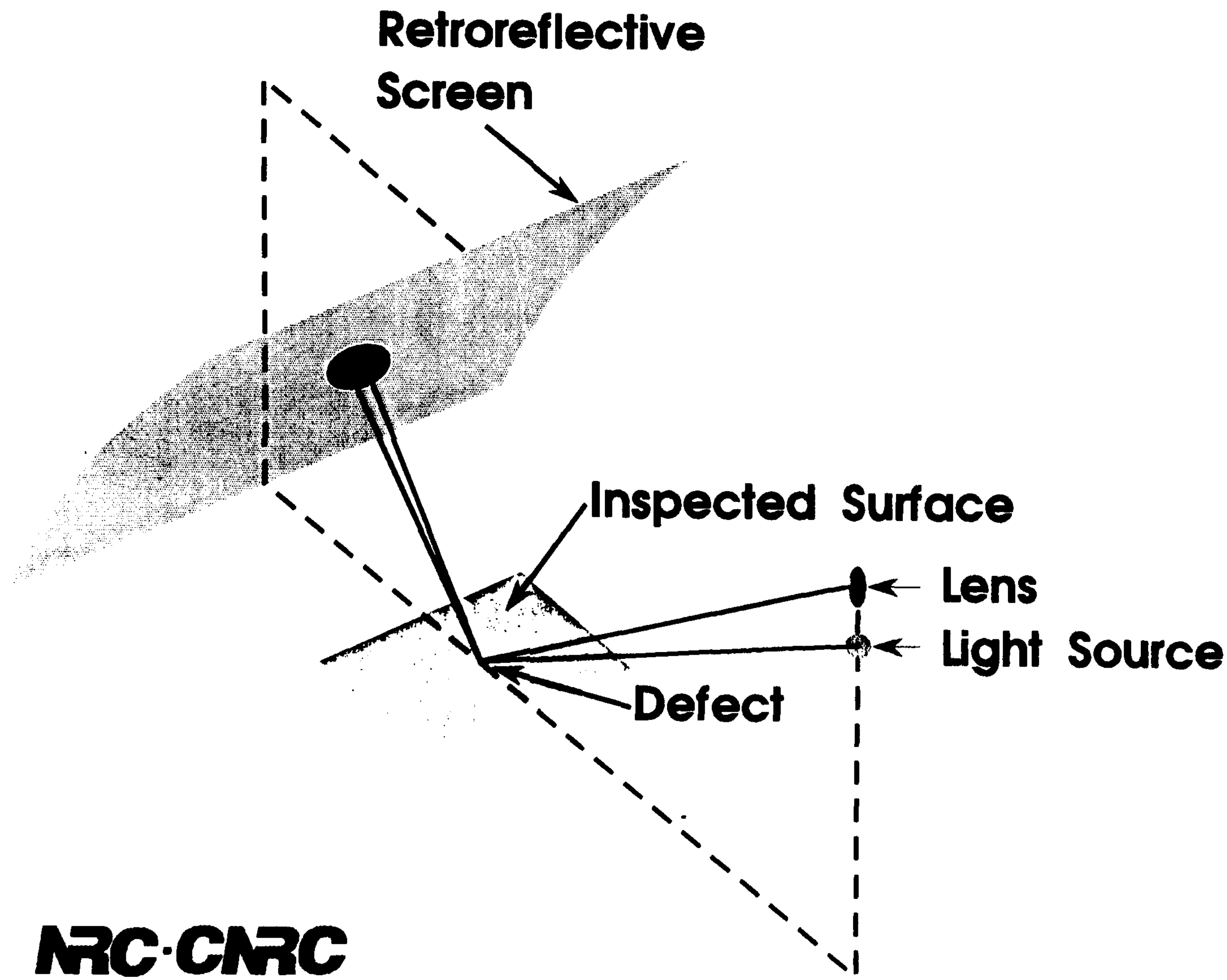
D Sight for corrosion detection in aircraft structures

OVERVIEW

- **D Sight optical set-up**
- **Corrosion Review and Survey**
- **Specimen acquisition**
- Accelerated corrosion testing
- Modeling of pillowing
- Inspections of specimens
- DAIS Modification
- Field Trials
- Conclusions and Future Work

NRC·CNRC

DIFFRACTO



NRC·CNRC

DIFFRACTO

D Sight for corrosion detection in aircraft structures

Corrosion survey results (1993)

NDI contacts, at 22 North American Airlines were asked for a corrosion severity rating on 11 locations for 29 types of aircraft.

Responses were received representing 16 Airlines, giving information on 16 types of aircraft.

Aircraft types for which greater than 3 responses were received:

DC-8, DC-9, DC-10 and MD-80
B727, B737, B747, B757 and B767
A300 and A320

NRC·CNRC

DIFFRACTO

D Sight for corrosion detection in aircraft structures

Corrosion survey results (1993) cont.

Ranking of Importance of sub-surface corrosion locations:

1) Horizontal Fuselage Lap Joints

2) Skin/Stringer Fuselage Joints

3) Skin/Rib Fuselage Joints

4) Circumferential Fuselage Lap Joints

5) Under Fastener Heads

6) Wing Skin/Spar Joints

NRC·CNRC

DIFFRACTO

...Aircraft ...ection

... Corrosion

... Strong Candidates:

- *Crevice Corrosion*
- *Exfoliation Corrosion*
- *Filliform Corrosion*

...ernal Aircraft Surfaces

Specimen acquisition

Aircraft:

B727-200, B737-200

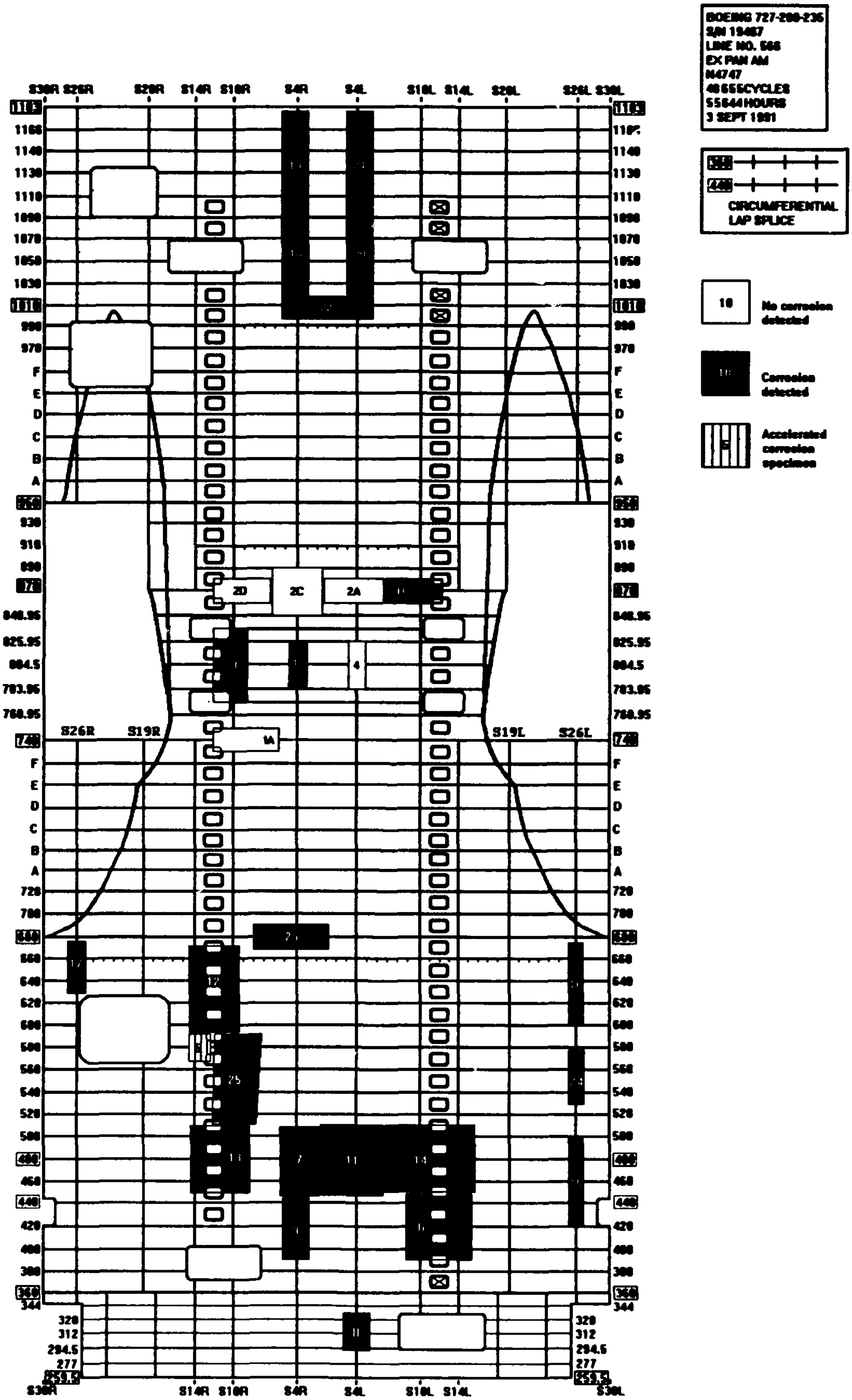
L1011

DC-9-14, DC-10-30

Total number of specimens: 138

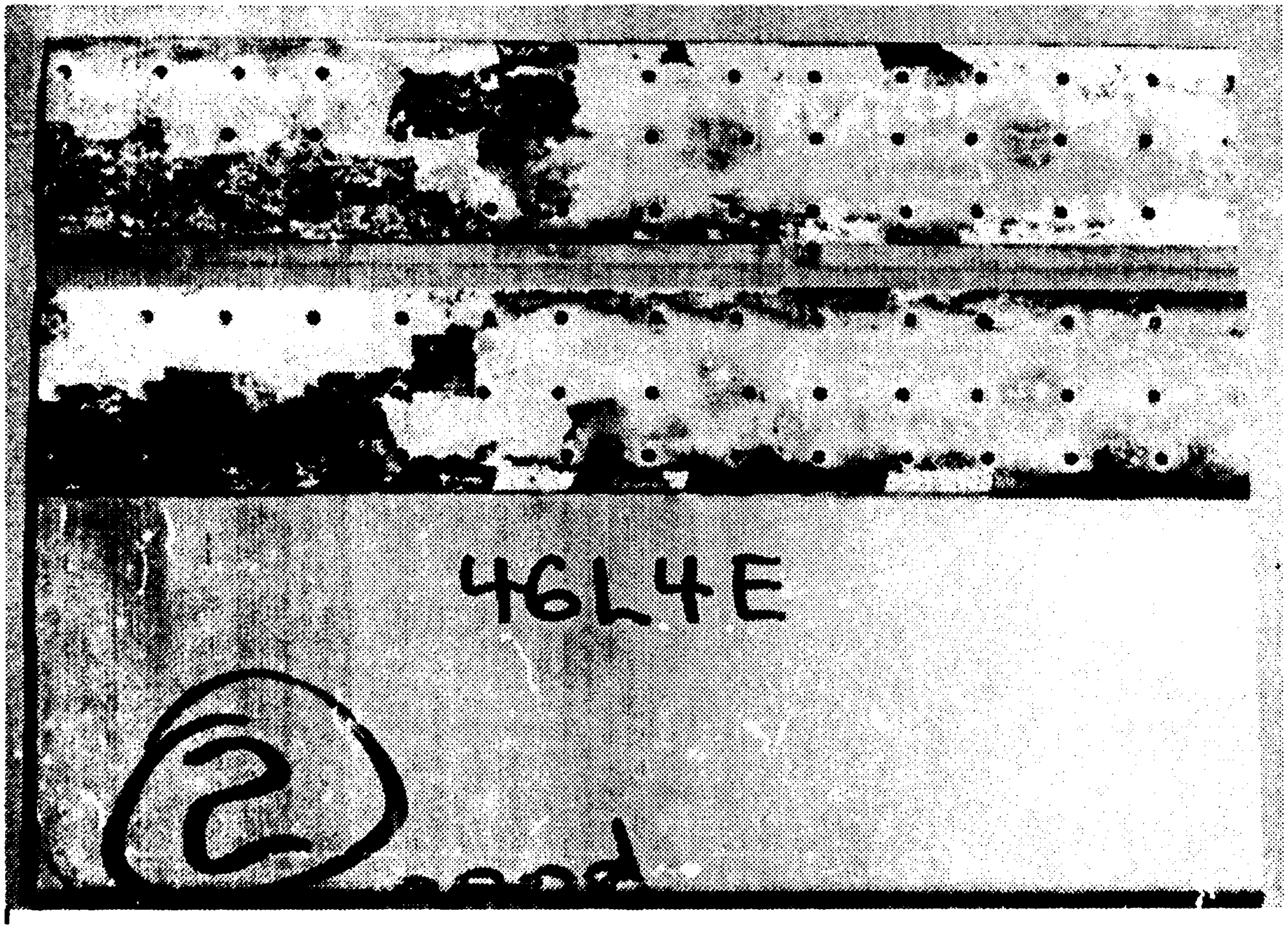
NRC·CNRC
DIFFRACTO

D Sight for corrosion detection in aircraft structures



NRC·CNRC DIFFRACTO

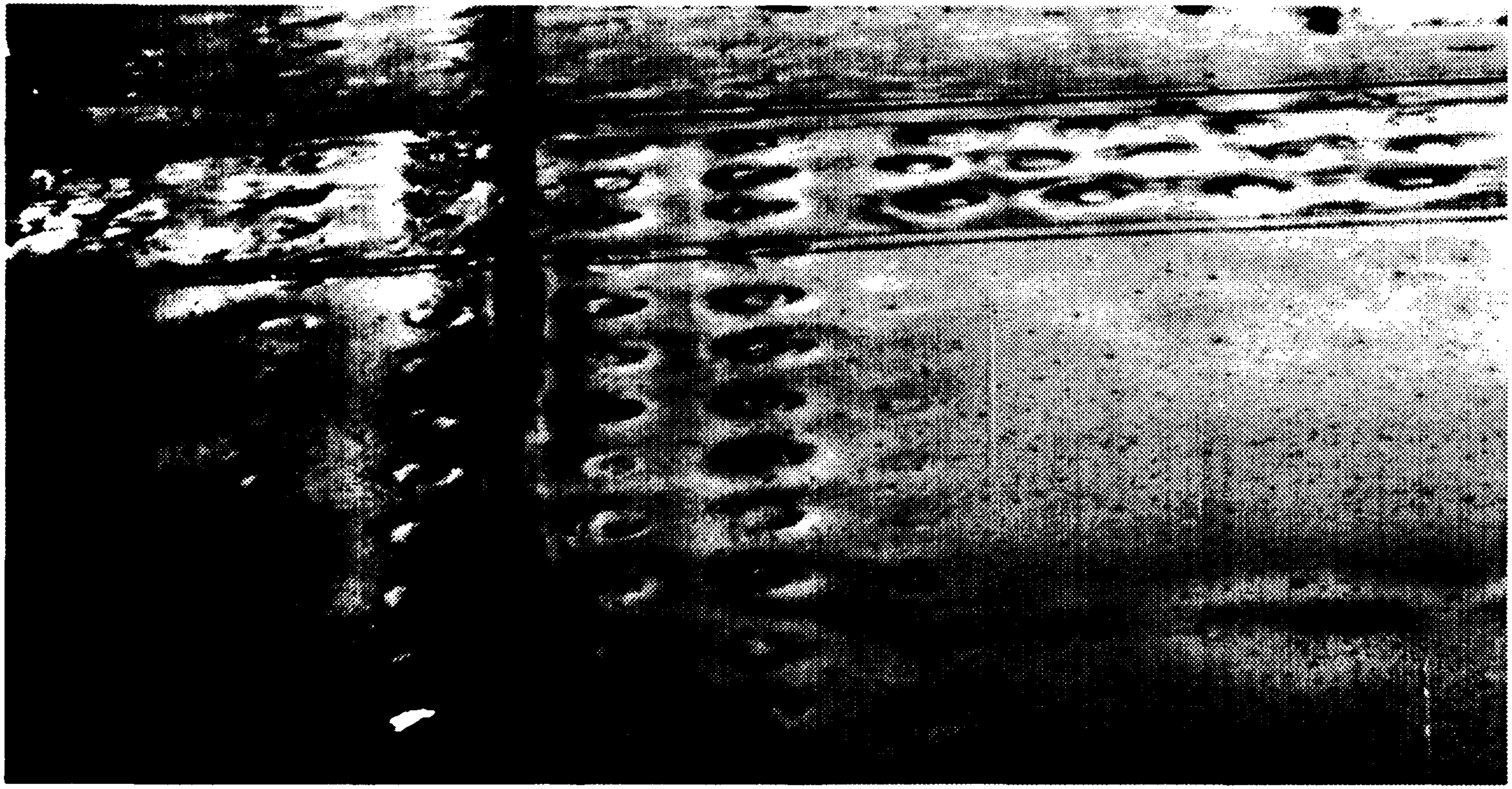
D Sight for corrosion detection in aircraft structures



Partly corroded lap splice

NRC·CNRC

D Sight for corrosion detection in aircraft structures



D Sight image of butt-splice
right side is corroded

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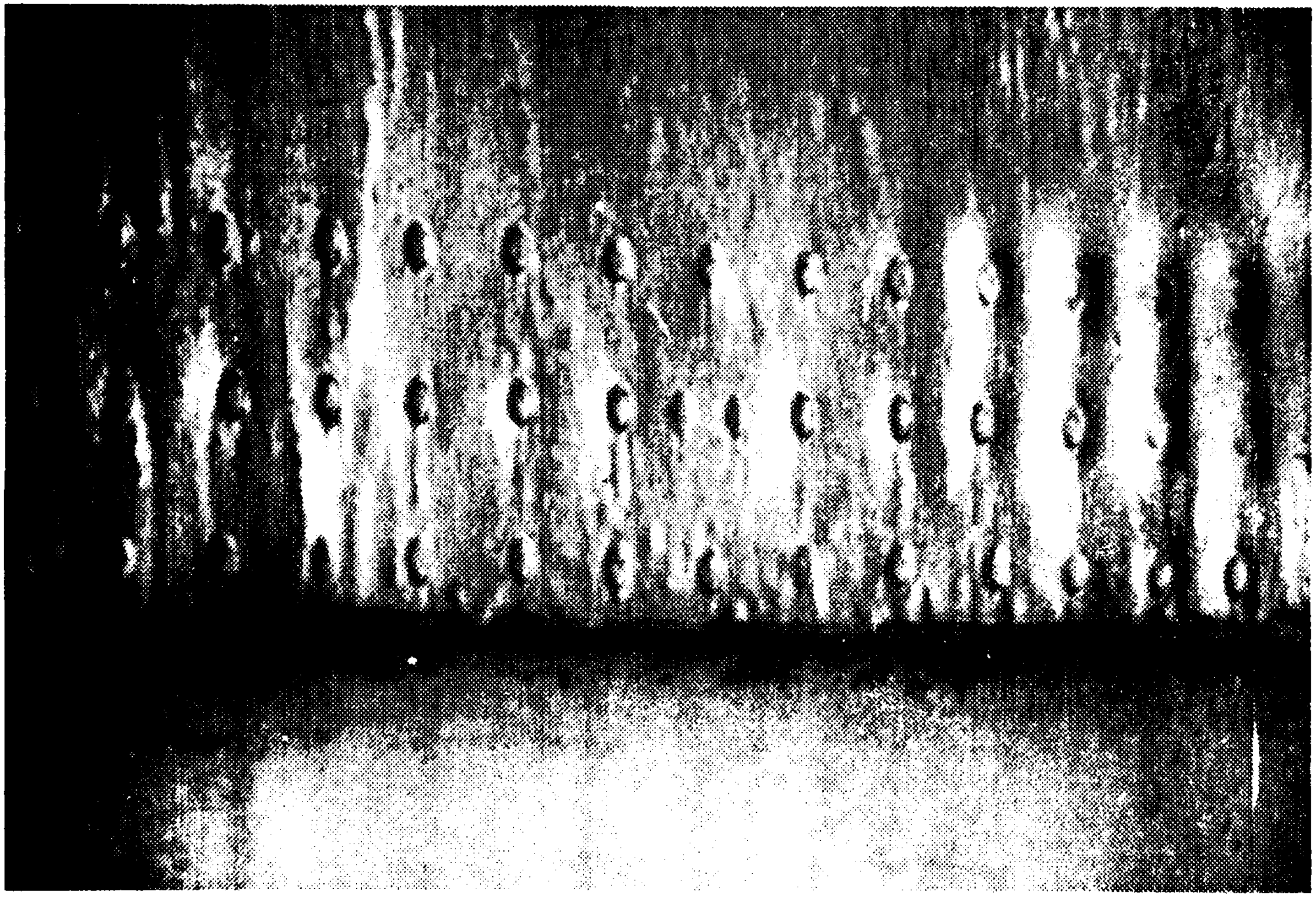
DIFFRACTO

D Sight for corrosion detection in aircraft structures



D Sight image of partly corroded lap splice

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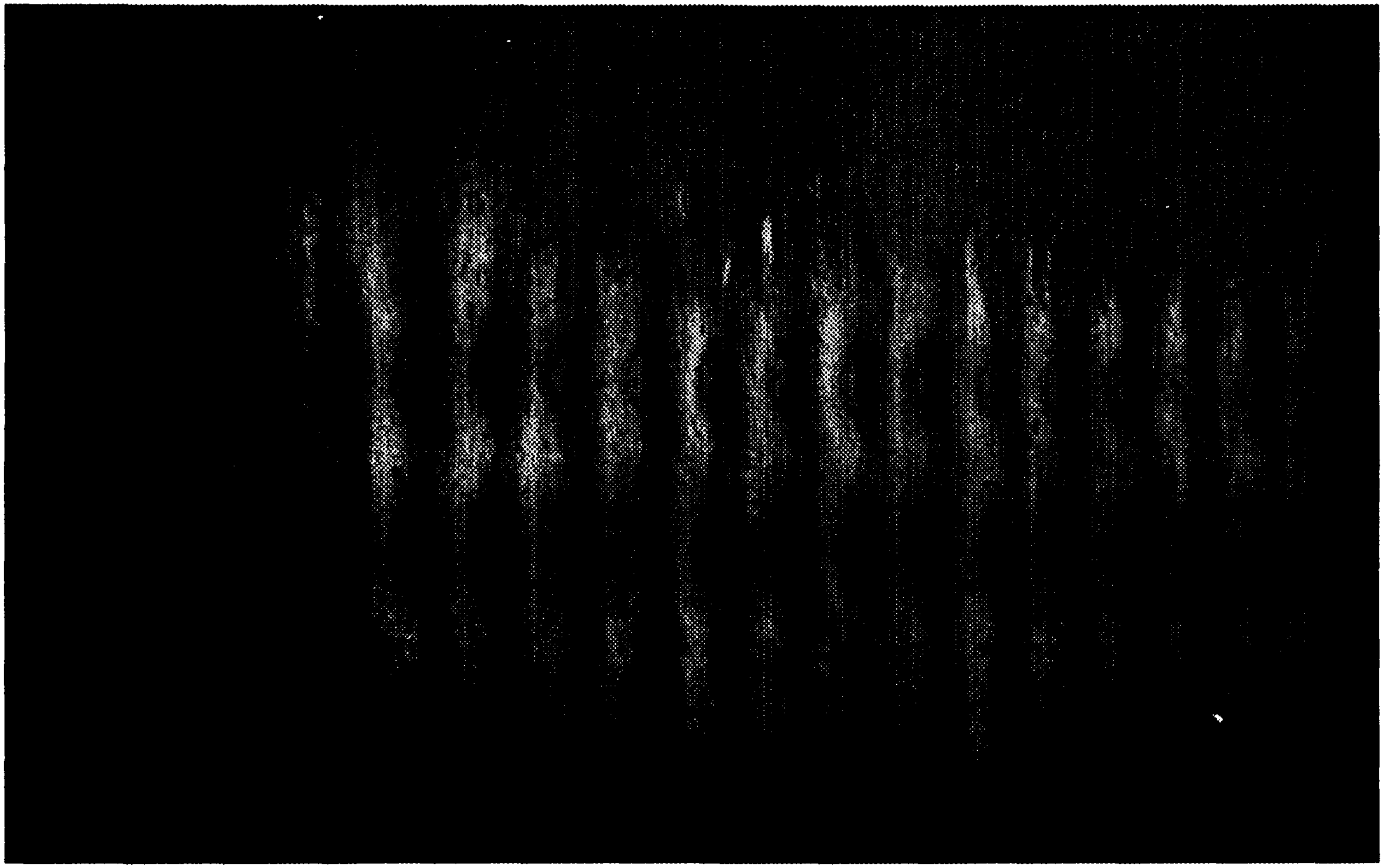
WINDSOR, ONTARIO N8T 3B7

D Sight for corrosion detection in aircraft structures



D Sight image - extensive abrasion and pillowing

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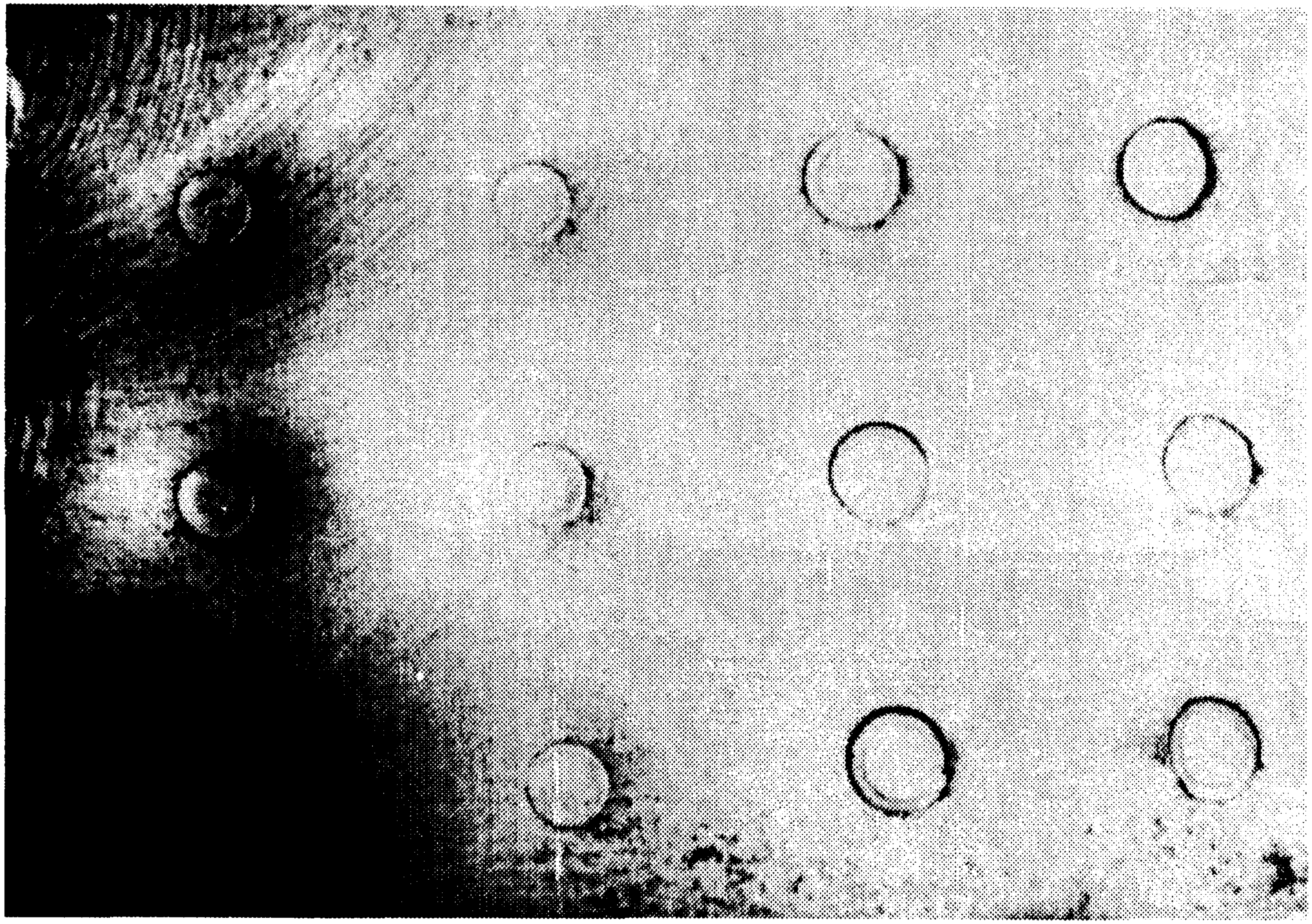
D Sight for corrosion detection in aircraft structures



Rivet head thinning due to excessive abrasion

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Chemical Characterization of Corrosion Products

Quantitative Techniques:

- ***X-ray photoelectron spectroscopy***
- ***Auger electron spectroscopy***

Qualitative Technique:

- ***X-ray diffraction analysis***

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Results of XPS and AES:

- *Atomic Ratio of Al : O = 1 : 3*
  (same as that of $Al_2O_3.3H_2O$)

Phases Identified by X-Ray Diffraction:

- *Amorphous and Crystalline $Al_2O_3.3H_2O$*
- *Crystalline $Al_2O_3.H_2O$*

Conclusion:

- *Major Corrosion Product is Aluminum Oxide Trihydrate*

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Pure Aluminum	Al	26.98	2.702
Aluminum Oxide	Al_2O_3	101.96	3.965
Aluminum Oxide Monohydrate	$Al_2O_3.H_20$	119.96	3.014

MODEL FOR PILLOWING DEFORMATION

- Volume Ratio of Corrosion Products to Aluminum Lost = 6.5

- Outer Skin Deflects under Uniform Pressure Due to Accumulation of Products.

- Timoshenko's Closed Form Solution for Plate Supported by Equidistant Columns

- **Ratio of Central Deflection to Thickness Lost = 4.**

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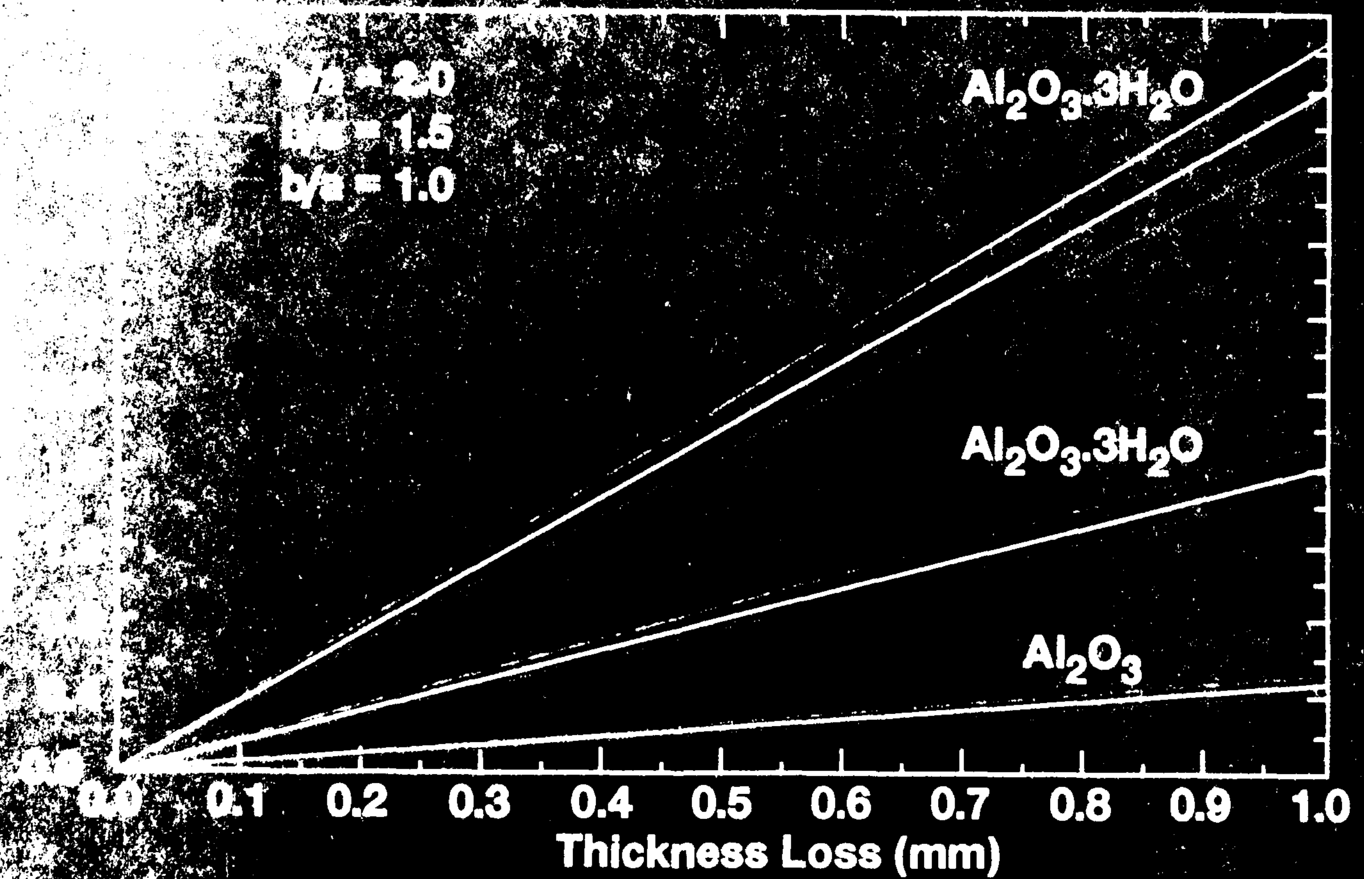
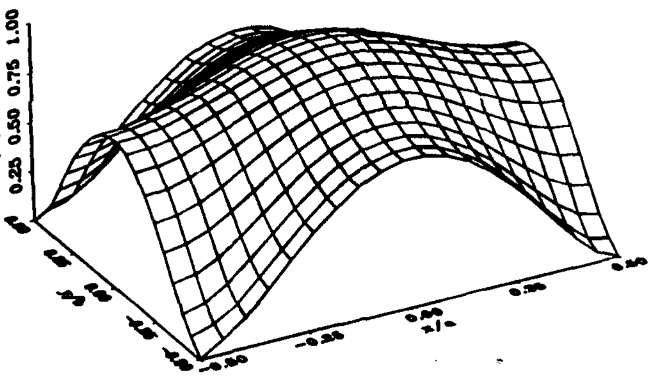
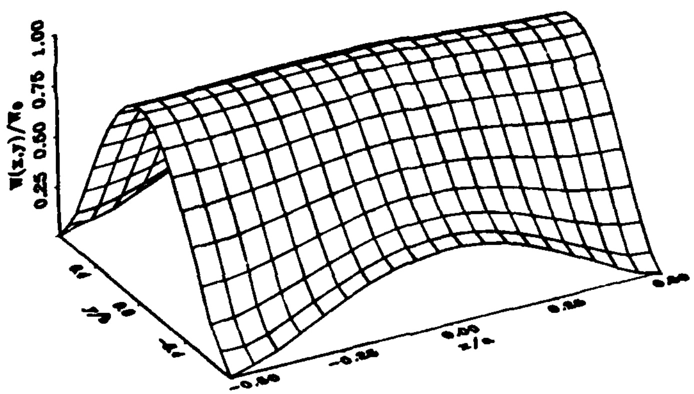
...um Pillowing Deflections



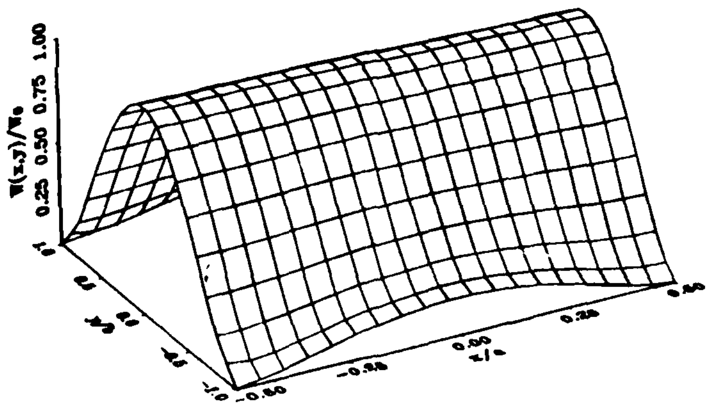
NRC CNRC



a) Rivet spacing ratio of 1.00



b) Rivet spacing ratio of 1.50



c) Rivet spacing ratio of 2.00

Deformed shapes for various rivet spacing ratios

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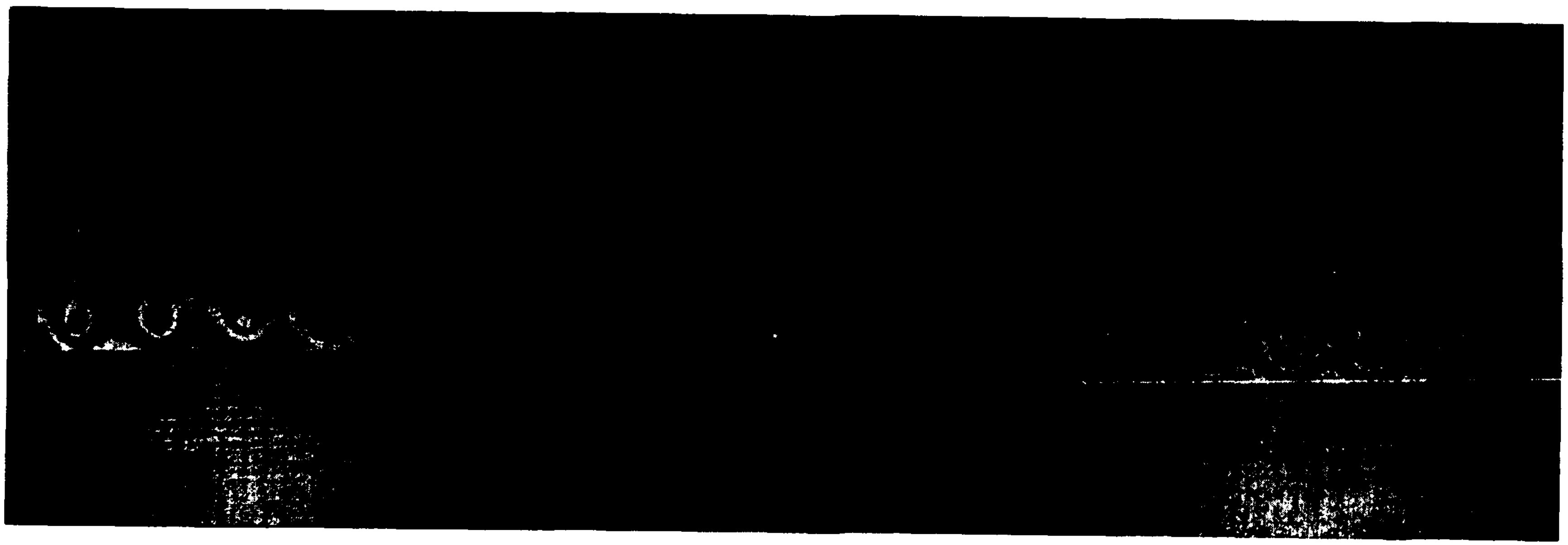

Shadow moiré inspection results at various corrosion exposure times.

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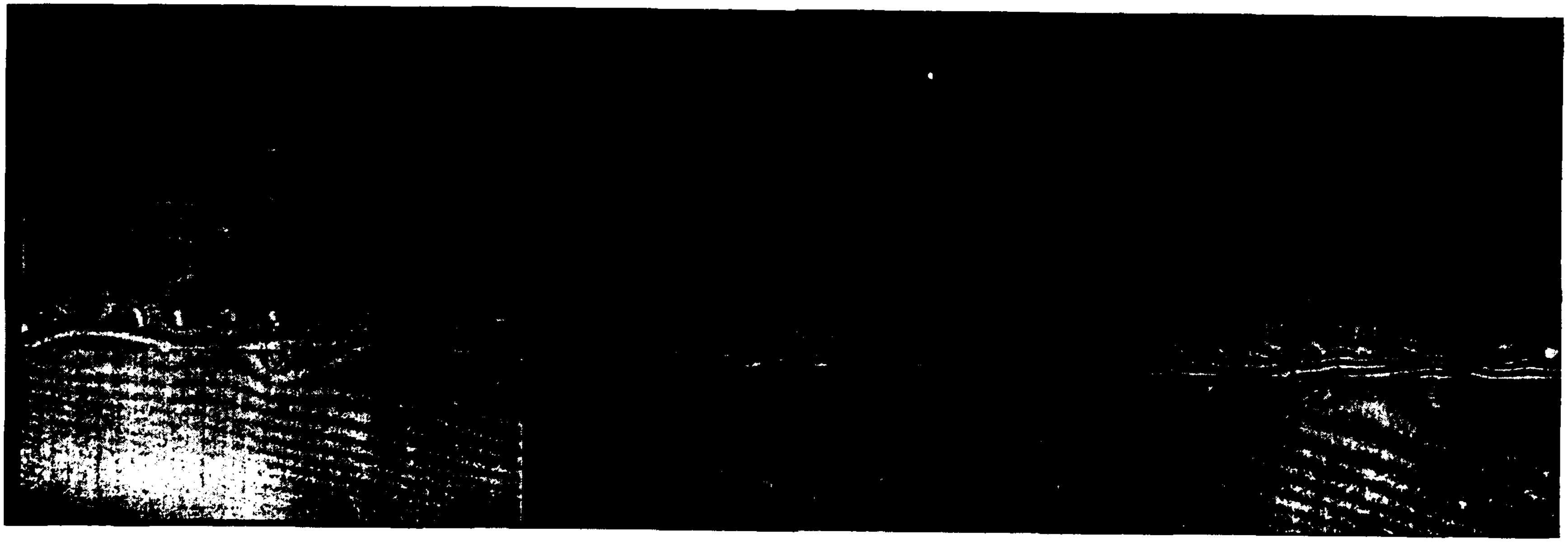
SHADOW MOIRE (200 LINES PER INCH)



409 HRS 629 HRS 1104 HRS

ACCELERATED CORROSION EXPOSURE TIME

DC-9 SPECIMEN 56T21A

Shadow moiré inspection results at various corrosion exposure times.

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D Sight for corrosion detection in aircraft structures

Specimen	D Sight result	Shadow Moir 751
56T21A	light corrosion	light corrosion
46L3E	mostly middle row but also light corrosion in top and bottom	mostly middle row (0.013")(7%)
43L6	all corroded	all corroded but less in top row (0.007")(4%)
51L2	bottom, middle and top rows corroded	bottom, middle but less in the top row (0.005")(3%)
46L4C	top, middle and bottom but not everywhere	top, middle and bottom but not everywhere 0.010")(5%)
46L4A	all corroded	all but light (0.005")(3%)
46L3C	all corroded	all corroded (0.007")(4%)
46L3A	middle and top row light corrosion	middle and top light corrosion (0.003-4")(2%)
43L7R	all corroded	all corroded (0.007")(4%)

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Low Frequency Eddy Current Instrument:

• *MIZ 40*	Zetec Incorporated Issaquah WA. 98027
• *PortaScan PS1*	Dupont NDT Instruments Huntington Beach, CA. 92649
• *PortaScan PS1-MIZ40 Ver 2.0*	Dupont NDT Instruments Huntington Beach, CA. 92649

Eddy Current Probe:

• *LFSL-D*	TYVIN

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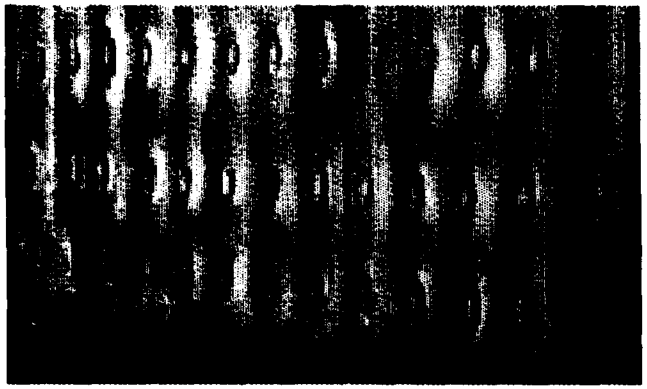
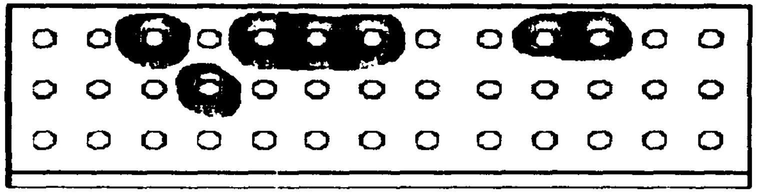
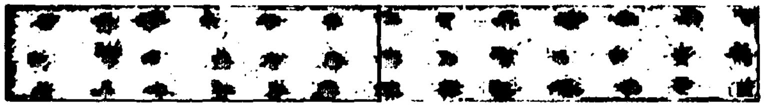


D Sight

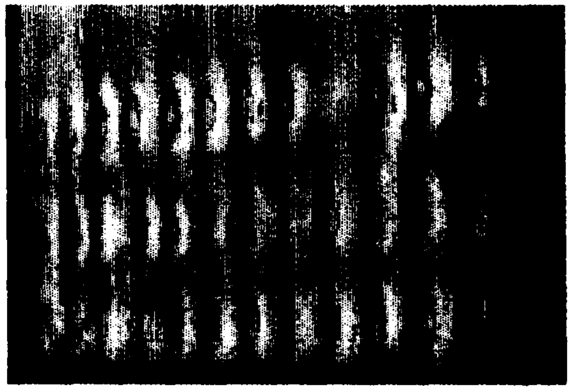


D Sight Inspection

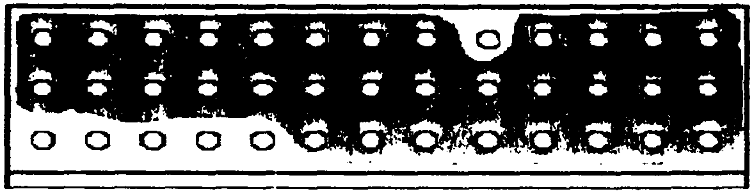


Eddy Current Inspection

46L4C



D Sight



D Sight Inspection

Eddy Current Inspection

46L4C

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D Sight for corrosion detection in aircraft structures

Good correlation between D Sight and eddy current maps			No correlation
No corrosion found	Corrosion found	D Sight found corrosion but no eddy current confirmation	eddy current indication but no D Sight confirmation
56T19A		56T21A(c)	
		56T1B	
		56T1A	
51R5	46L4C(a)(c)	46L3A(a)(c)	51R2(b)
51R3	43L6(a)(c)	46L3E(a)(c)	51R1(b)
51L3	51R6	51L2(a)(c)	43L3
46R3E	51R4	51L2	
46L6	43L7R(a)(c)	39L3	
43L4	46L3C(a)(c)	43L2	
43L6	46L4A(a)(c)	46L4C	
46L3A	39L1	46L4A	
52L2	46R3C	43L7R	
52L1	46R3A		
	43L5		
	43R2		
	46L2		
Total number			
11	13	12	3

(a) Inspected after prolonged corrosion exposure
(b) Eddy current signal due to paint
(c) Corrosion found by shadow moiré

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D Sight for corrosion detection in aircraft structures

	A	B	C	D	E	F	G	H	I	J	K
2		EDDY CURRENT TESTING									
3		STANDARD DEPTH OF PENETRATION									
4											
5	Frequency	Conductivity in % I.A.C.S.					Low Frequency Spot Probes, Ferrite Shielded				
6		32	34	36	38	40	Probe Diameter (in.)				
7											
8	100 Hz	0.46	0.446	0.433	0.422	0.411	.875/1.0/1.125				
9	200 Hz	0.325	0.315	0.306	0.298	0.291	.875/1.0/1.125	0.687			
10	300 Hz	0.265	0.257	0.25	0.244	0.237	.875/1.0/1.125	0.687			
11	400 Hz	0.23	0.223	0.217	0.211	0.206	.875/1.0/1.125	0.687			
12	500 Hz	0.206	0.199	0.194	0.189	0.184	.875/1.0/1.125	0.687	0.562		
13	600 Hz	0.188	0.182	0.177	0.172	0.168	.875/1.0/1.125	0.687	0.562		
14	700 Hz	0.174	0.169	0.164	0.159	0.153	.875/1.0/1.125	0.687	0.562		
15	800 Hz	0.163	0.153	0.153	0.149	0.145	.875/1.0/1.125	0.687	0.562		
16	900 Kz	0.153	0.149	0.144	0.141	0.137	.875/1.0/1.125	0.687	0.562		
17	1 KHz	0.145	0.141	0.137	0.133	0.13	.875/1.0/1.125	0.687	0.562		
18	2 KHz	0.103	0.1	0.097	0.094	0.092		0.687	0.562		
19	3 KHz	0.084	0.081	0.079	0.077	0.075			0.562		
20	4 KHz	0.073	0.071	0.069	0.067	0.065				0.5	
21	5 KHz	0.065	0.063	0.061	0.06	0.058				0.5	
22	6 KHz	0.050	0.058	0.056	0.054	0.053				0.5	
23	7 KHz	0.055	0.053	0.052	0.05	0.049				0.5	
24	8 KHz	0.051	0.05	0.048	0.047	0.046				0.5	
25	9 KHz	0.048	0.047	0.046	0.044	0.043				0.5	
26	10 KHz	0.046	0.045	0.043	0.042	0.041				0.5	
27	20 KHz	0.033	0.032	0.031	0.03	0.029				0.5	0.25/0.375
28	30 KHz	0.027	0.026	0.025	0.024	0.024					0.25/0.375
29	40 KHz	0.023	0.022	0.022	0.021	0.021					0.25/0.375
30	50 KHz	0.021	0.02	0.019	0.019	0.018					0.25/0.375
31			(c)McDonnell Douglas Aerospace							(c)Tyvin Inc.	
32											
33	B727, Stringer 10, Skin Material 2024 T3, nominal 0.050 in.thick, Conductivity Range 33-35 % I.A.C.S.										
34											
35	DC 9 ,Longeron No.1, Skin Material 2014 T6, nominal 0.050 in. thick, Conductivity Range 38-40% I.A.C.S.										
36											
37	DC10 ,BUTT Joint, Skin Material 2024 T3, nominal 0.070 in. thick, Conductivity Range 33-35% I.A.C.S.										

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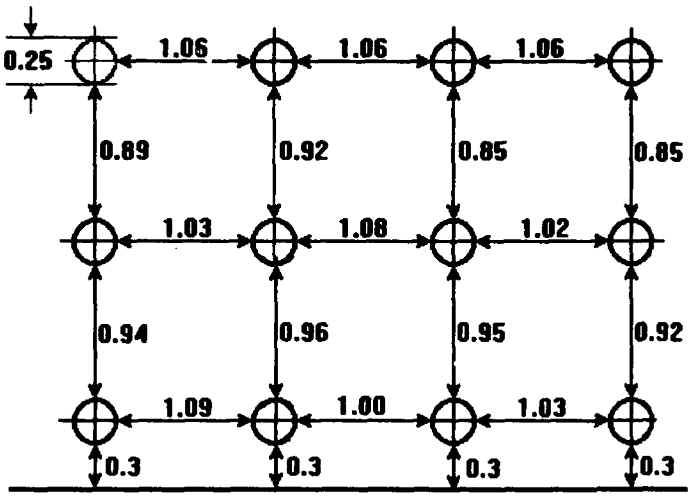
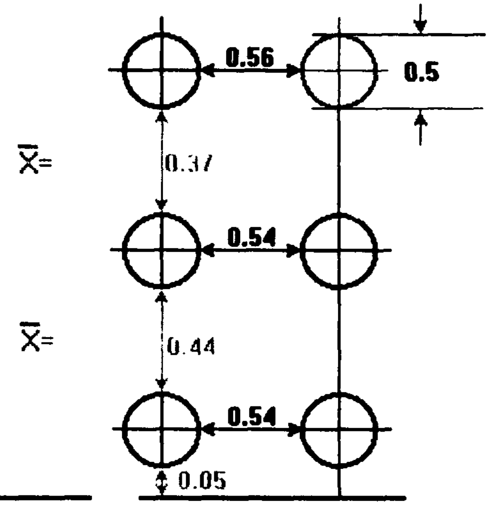
LIMITED EDDY CURRENT PROBE ACCESS FOR CORROSION DETECTION

BOEING 727 LAP SPLICE



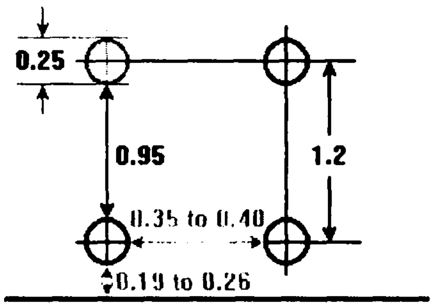
Flush Rivet, Spacing sample



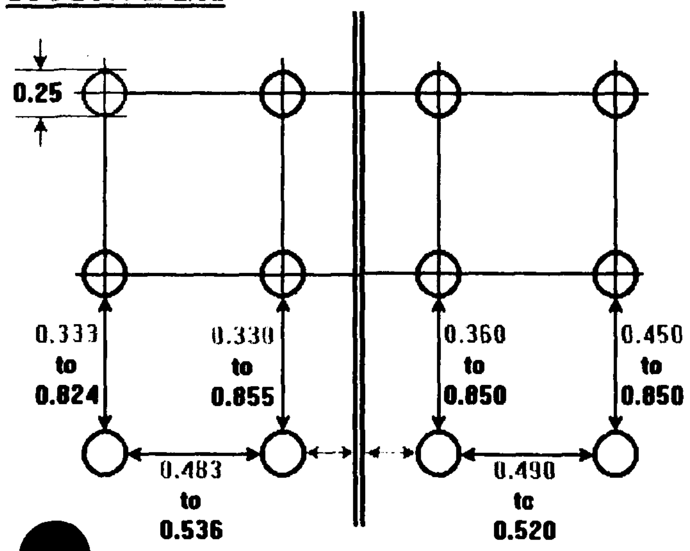
Mushroom Rivet

Note: A sampling of spacing between mushroom head rivets installed at fuselage stations ranged between 0.28 and 0.40 inches.

DC 9 LAP SPLICE

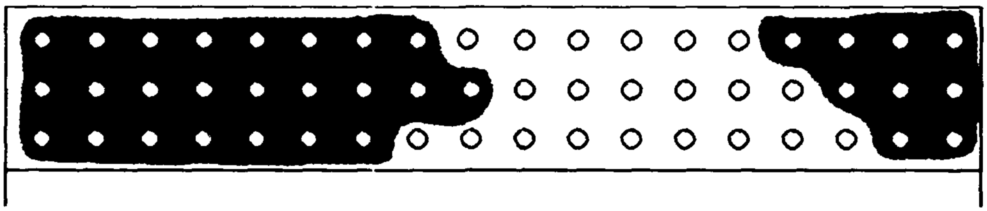


DC 9 BUTT SPLICE

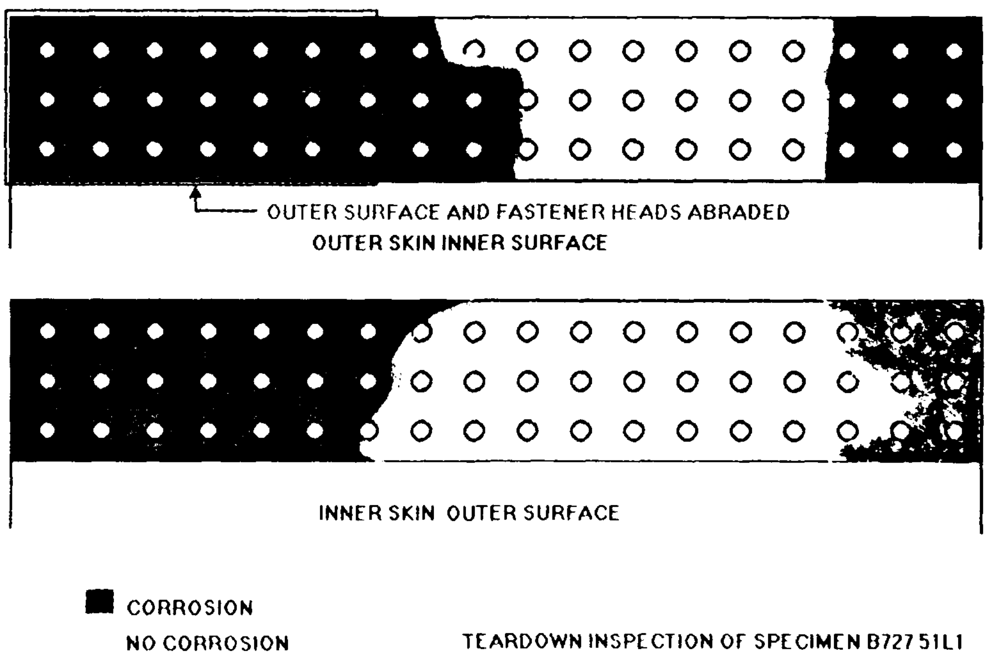


D Sight for corrosion detection in aircraft structures

D Sight image



D Sight corrosion map



Specimen 51L1 D Sight and teardown maps of corrosion

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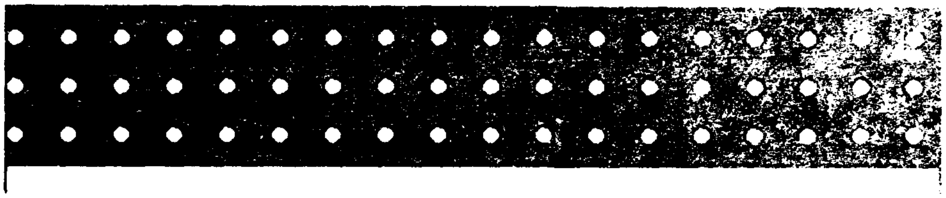
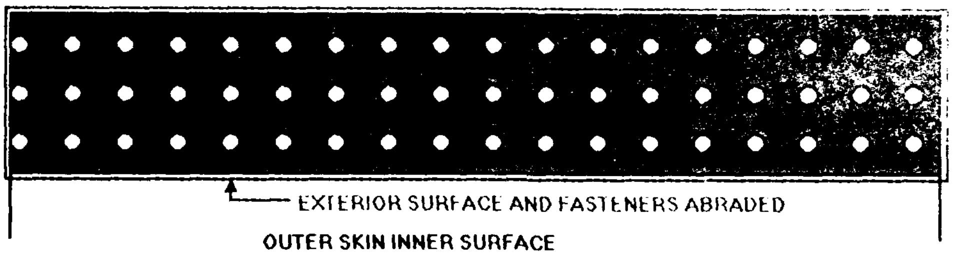
D Sight for corrosion detection in aircraft structures

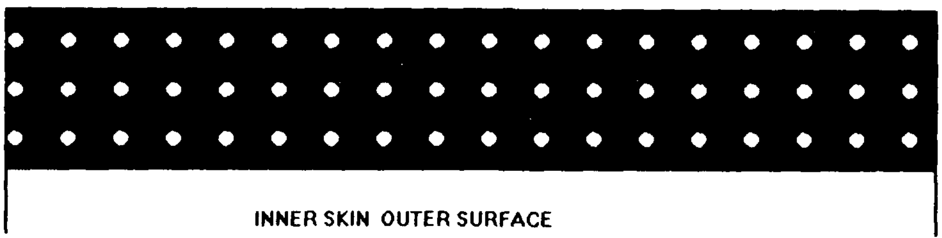
D Sight image



D Sight corrosion map



OUTER SKIN INNER SURFACE



INNER SKIN OUTER SURFACE

■ CORROSION
NO CORROSION

TEARDOWN INSPECTION OF SPECIMEN B727 51L6

Specimen 51L6 D Sight and teardown maps of corrosion

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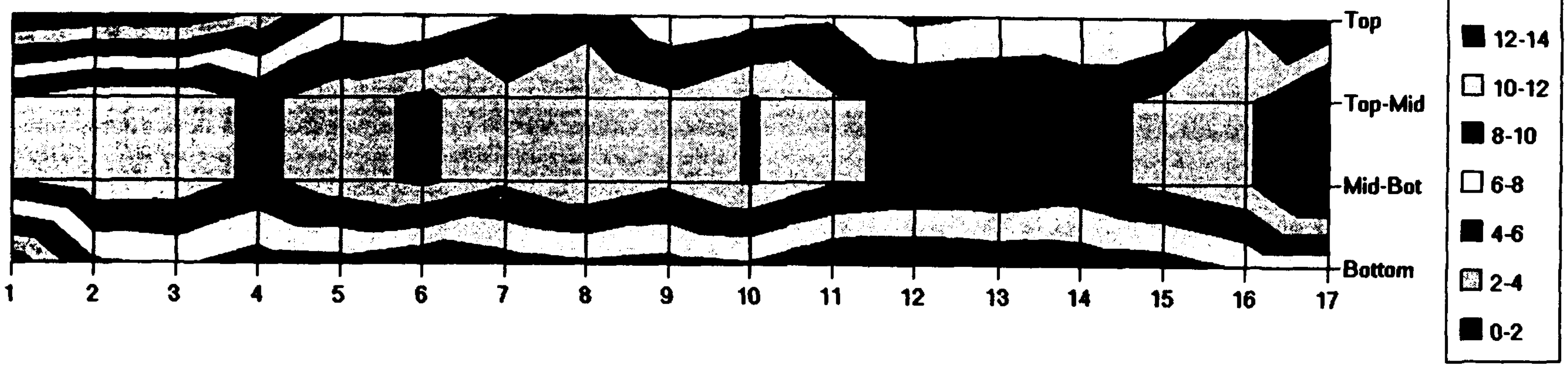
D Sight for corrosion detection in aircraft structures

% thickness loss 51L6



DIFFRACTO

D Sight for corrosion detection in aircraft structure

Field Trials

ARINC (USAF) - Tinker AFB

B727 and KC-135

FAA AANC - Albuquerque

B737

Air Canada - Winnipeg

DC-9, A320, B727

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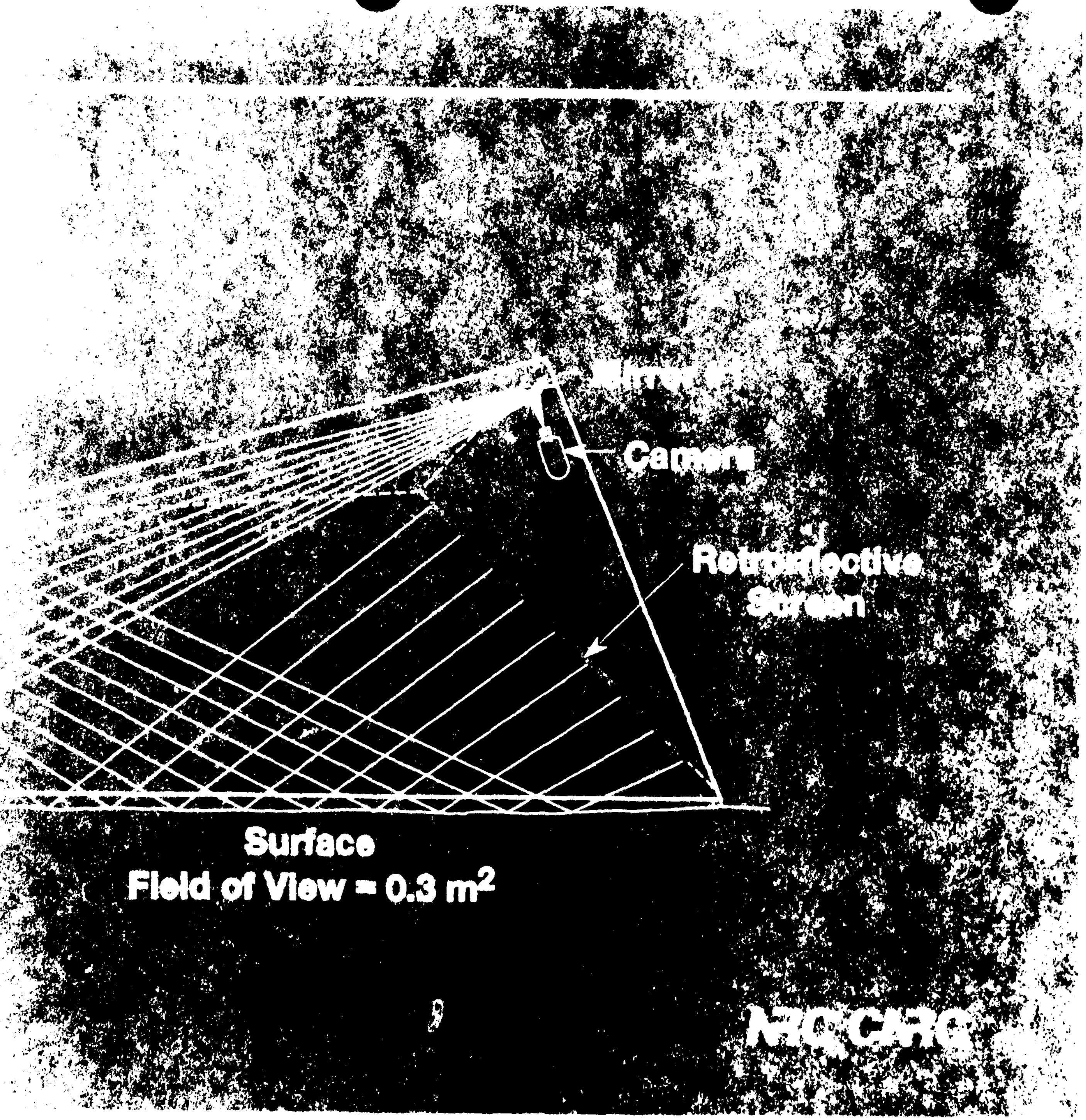
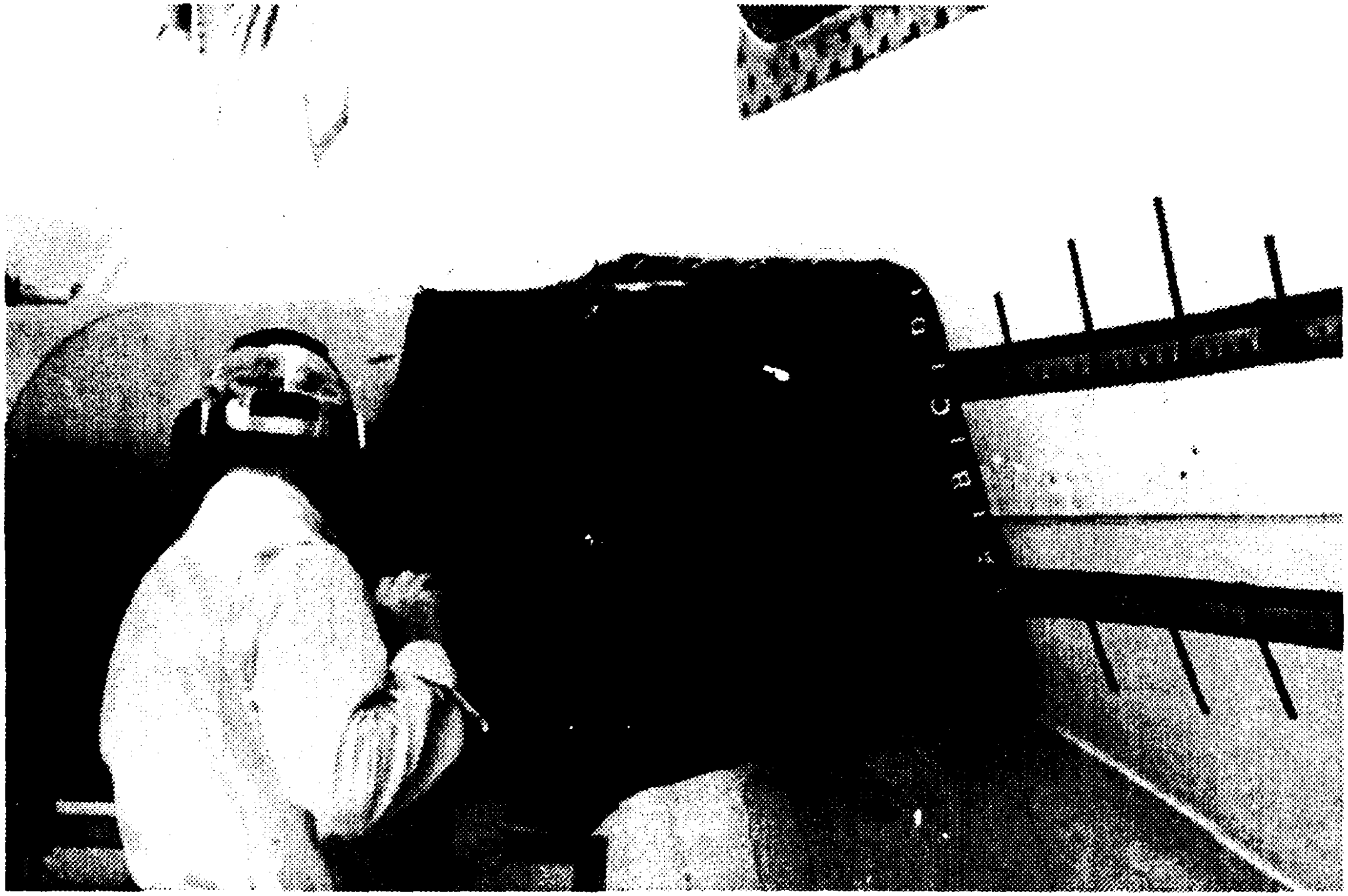

Camera
Retroreflective
Screen
Surface
Field of View = 0.3 m²

D Sight for corrosion detection in aircraft structures



ARINC evaluations Phase 1 - DAIS 500

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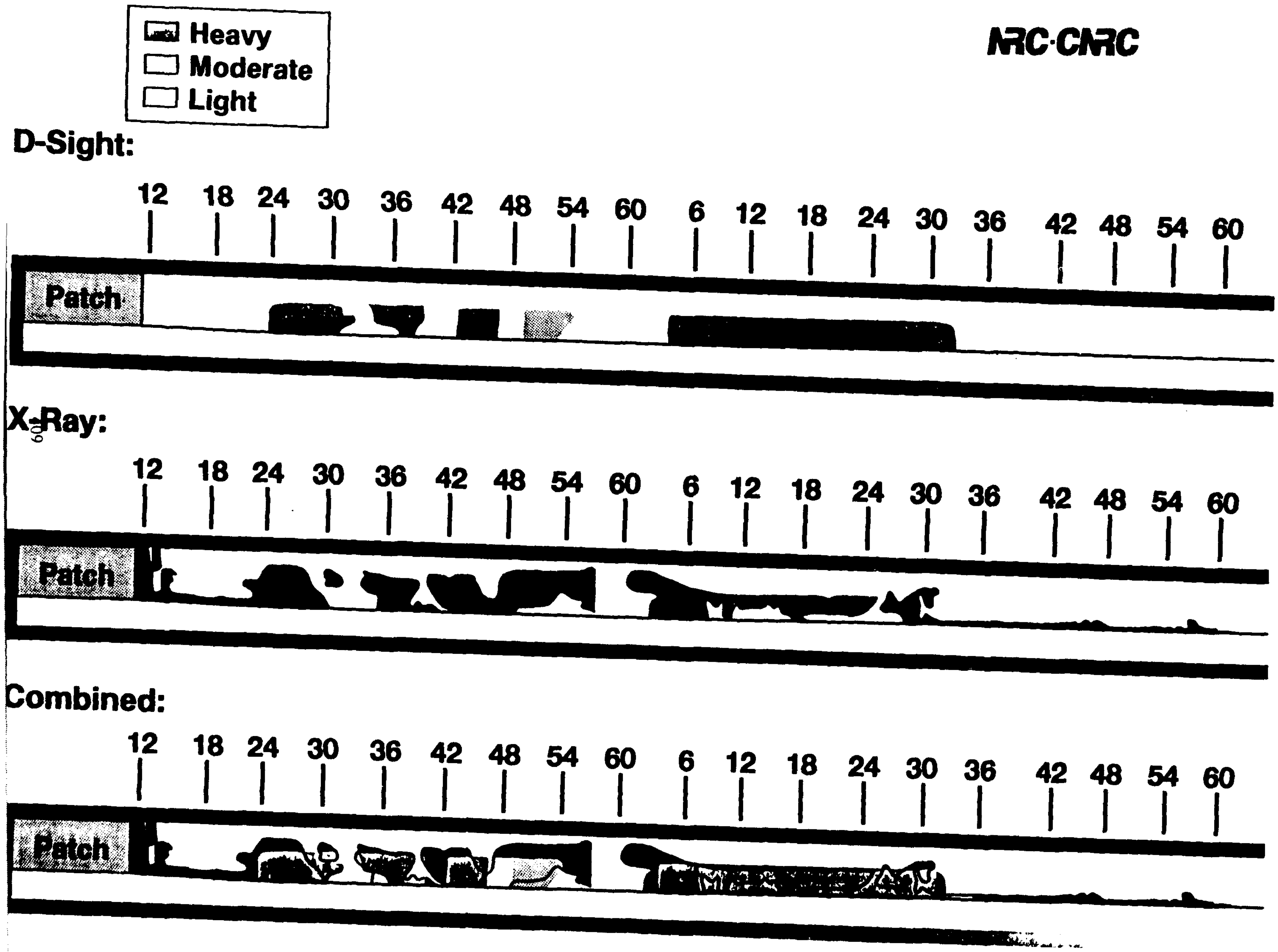
DIFFRACTO



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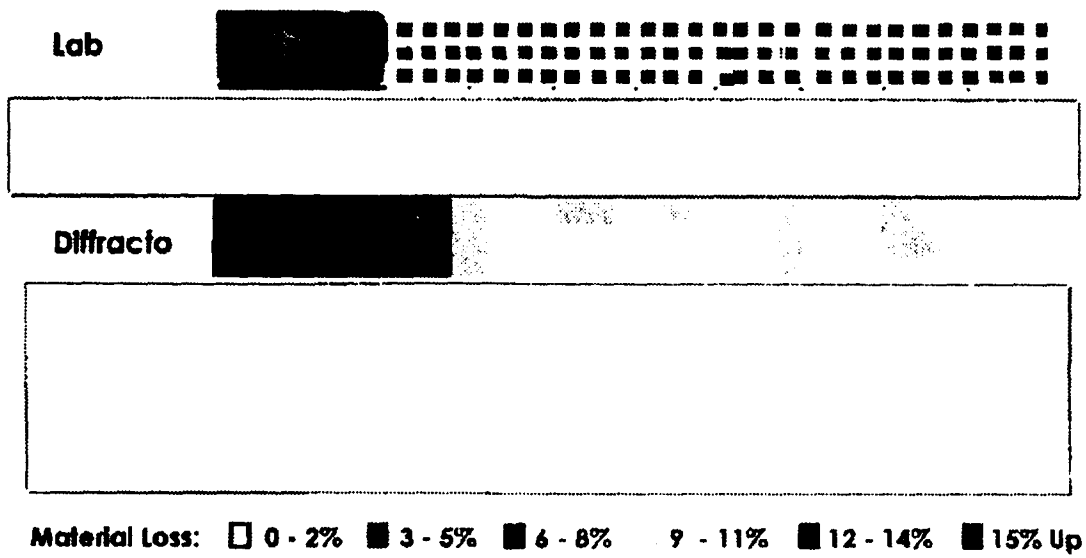
Heavy
Moderate
Light
D-Sight:
12 18 24 30 36 42 48 54 60 6 12 18 24 30 36 42 48 54 60
Patch
X-Ray:
12 18 24 30 36 42 48 54 60 6 12 18 24 30 36 42 48 54 60
Patch
Combined:
12 18 24 30 36 42 48 54 60 6 12 18 24 30 36 42 48 54 60
Patch

AREA 5 SHEET 1
VENDOR IMAGE COMPARISON

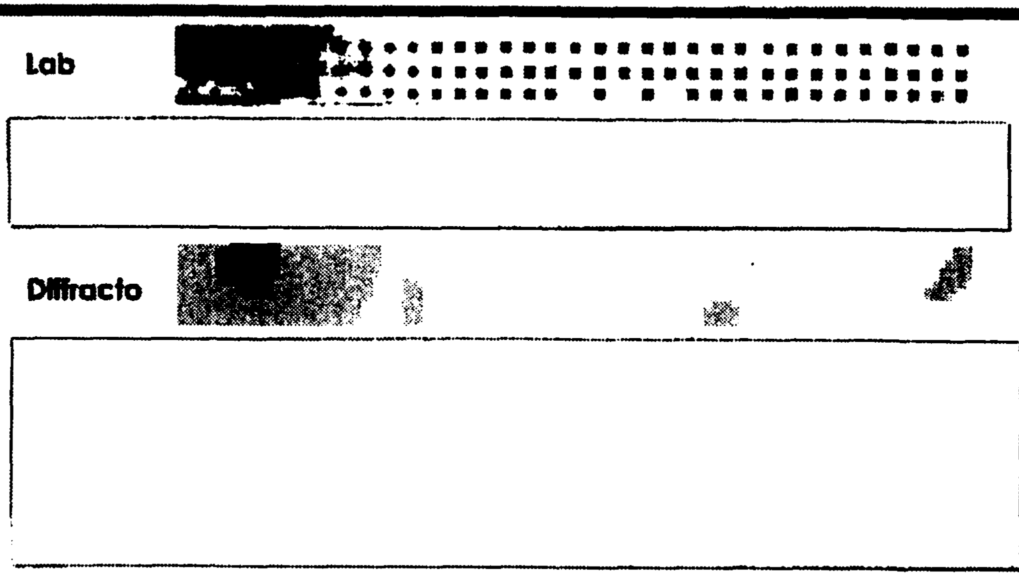


SD/OSE/AO/09-10-93

Slide Number 32

NRC·CNRC

AREA 1 SHEET 1
VENDOR IMAGE COMPARISON



Material Loss: ☐ 0 - 2% ■ 3 - 5% 6 - 8% 9 - 11% ■ 12 - 14% ■ 15% Up

SD/OSE/AO/09-10-93 Slide Number 31

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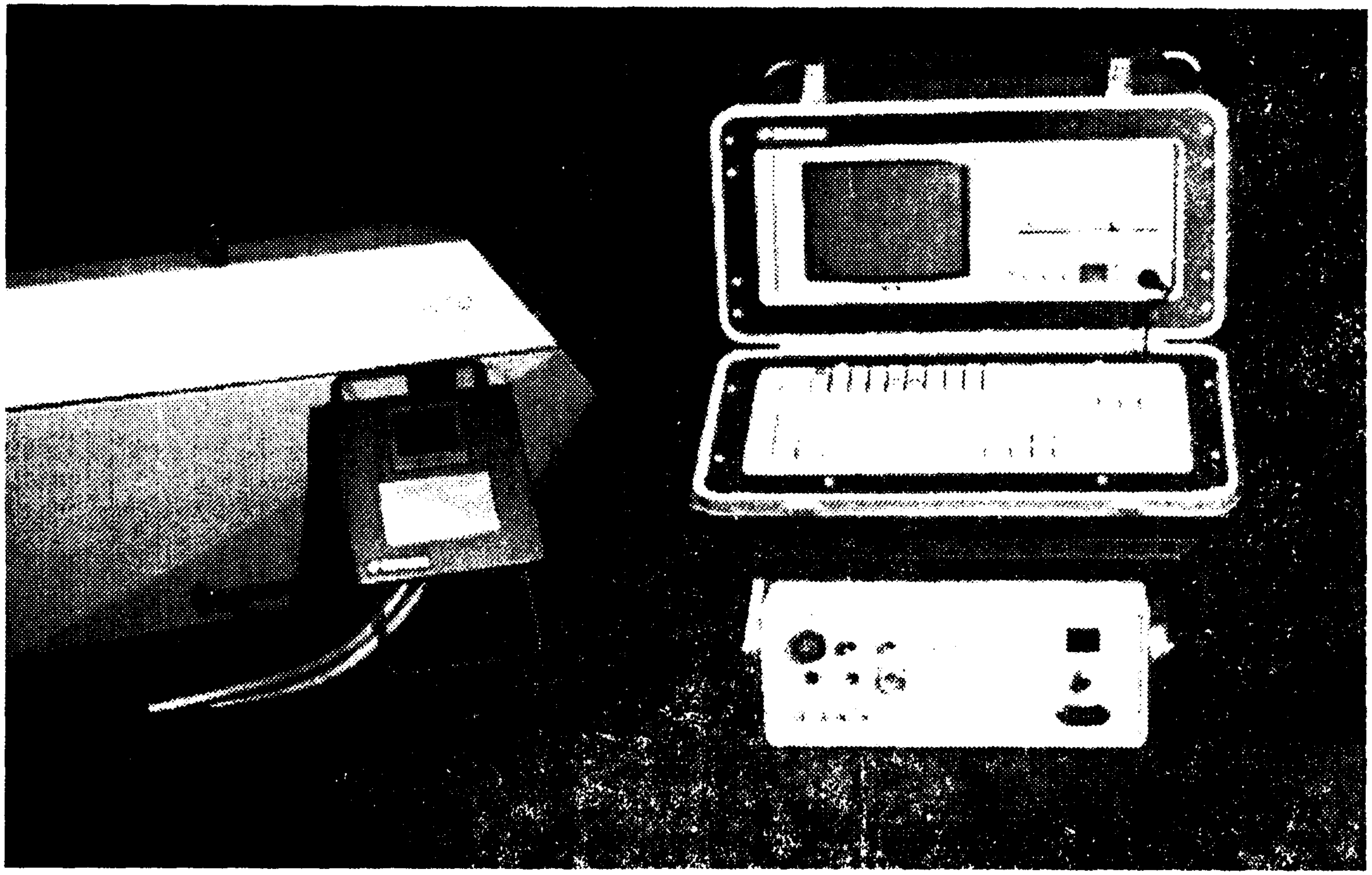
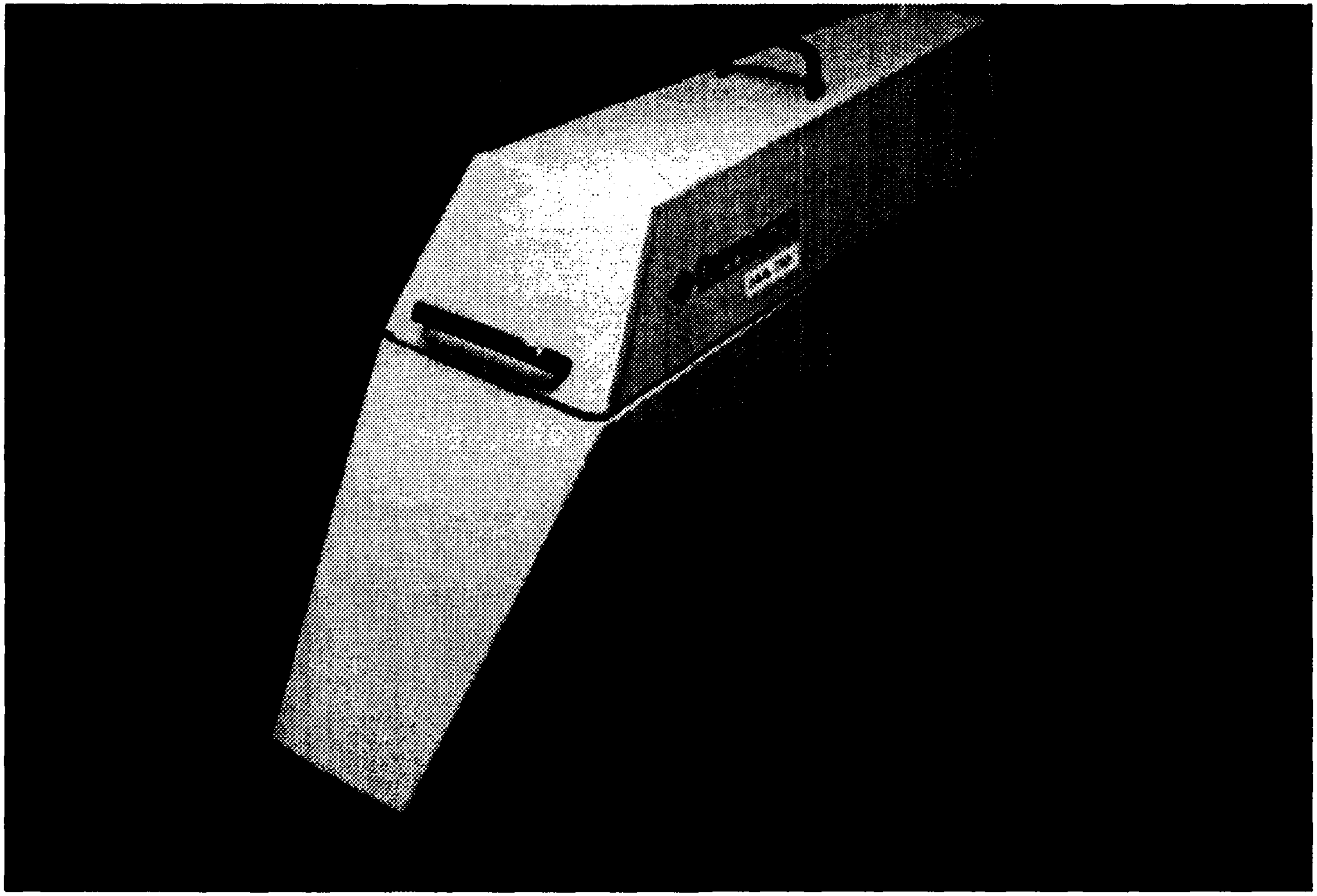
D Sight for corrosion detection in aircraft structures



DAIS 250C equipment: inspection head, pendant, computer and power supply.

D Sight for corrosion detection in aircraft structures



DAIS - 250C

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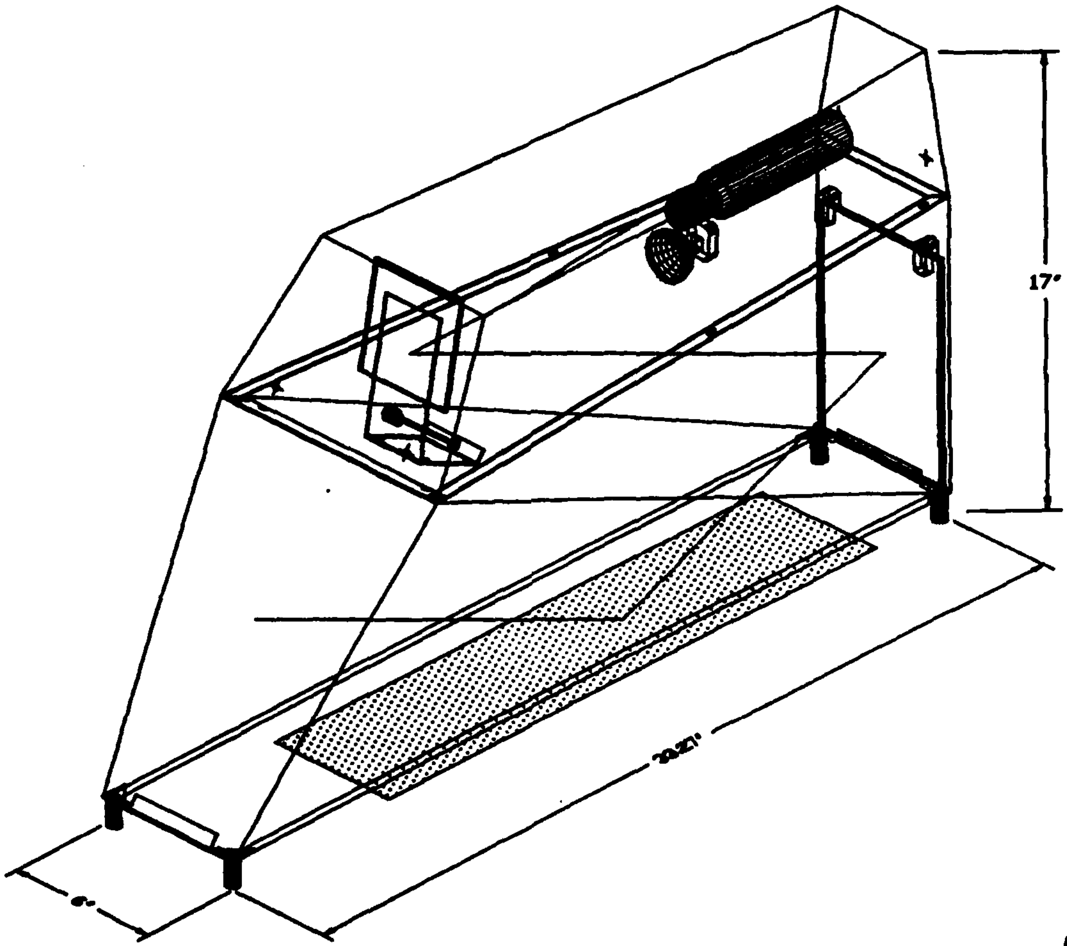
D Sight for corrosion detection in aircraft structures



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D Sight for corrosion detection in aircraft structures

DAIS-250C at AANC Sept. 1993

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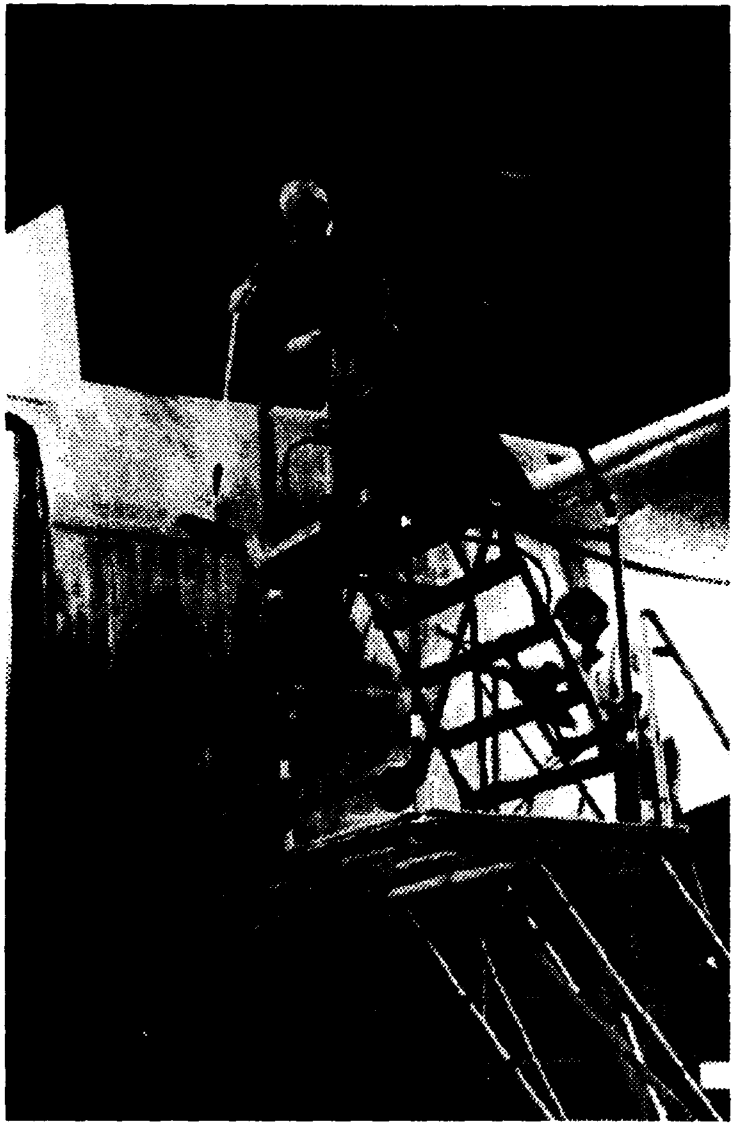
D Sight for corrosion detection in aircraft structures



Aircraft surface preparation - highliting with a fluid.

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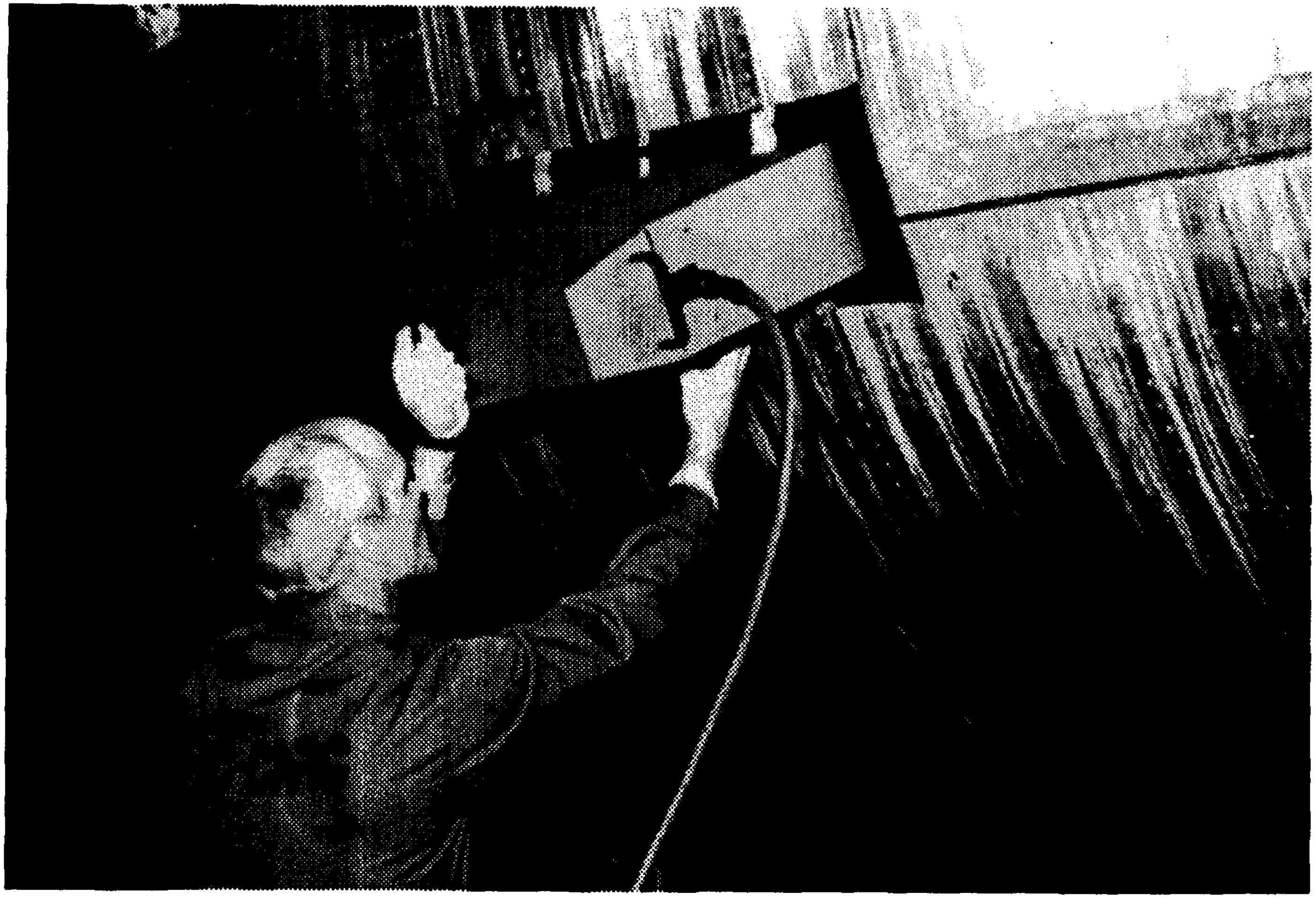
D Sight for corrosion detection in aircraft structures



AANC, Sept 1993 - DAIS

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D Sight for corrosion detection in aircraft structures

DAIS 250C head weight: 7 lb

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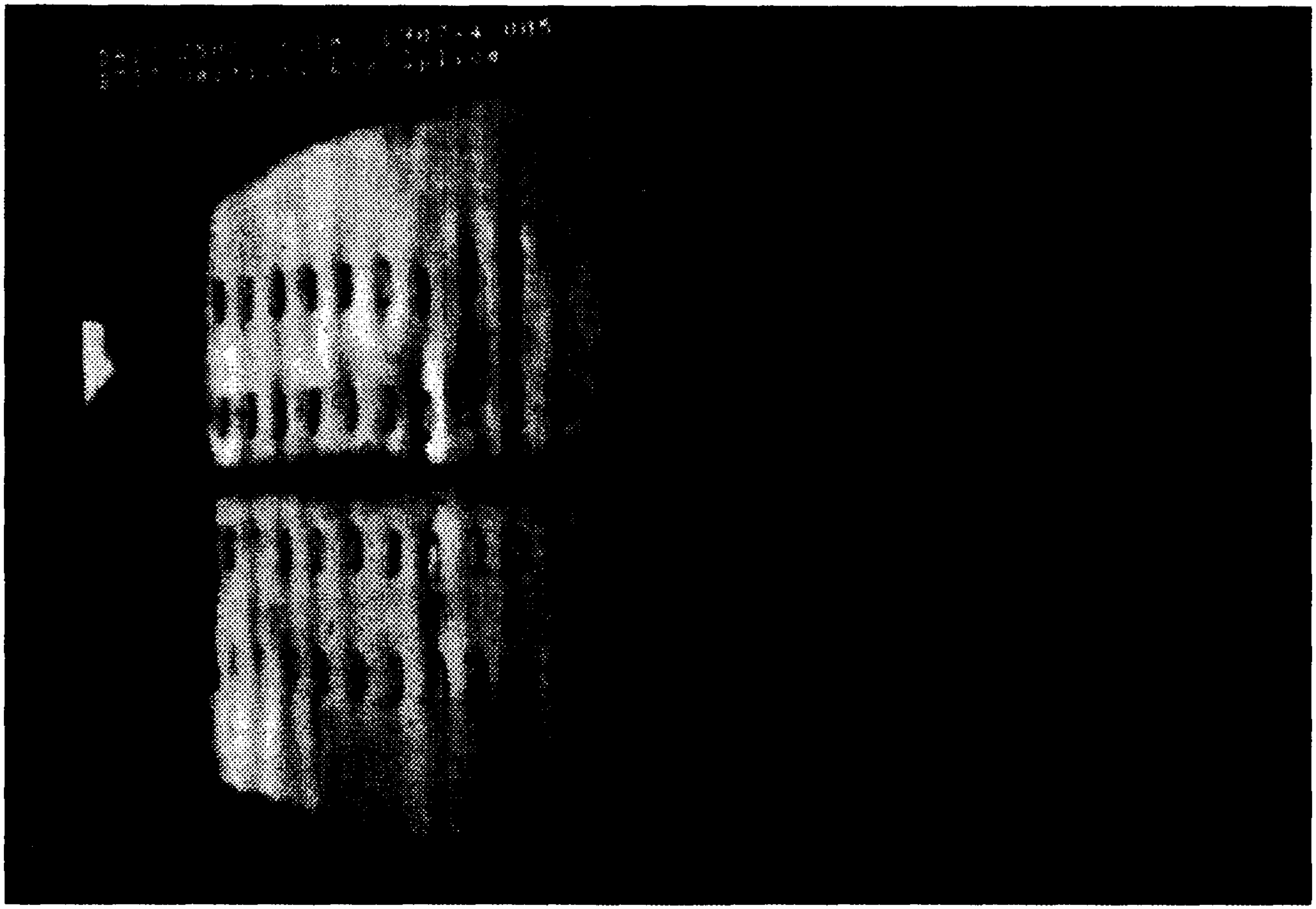
D Sight for corrosion detection in aircraft structures

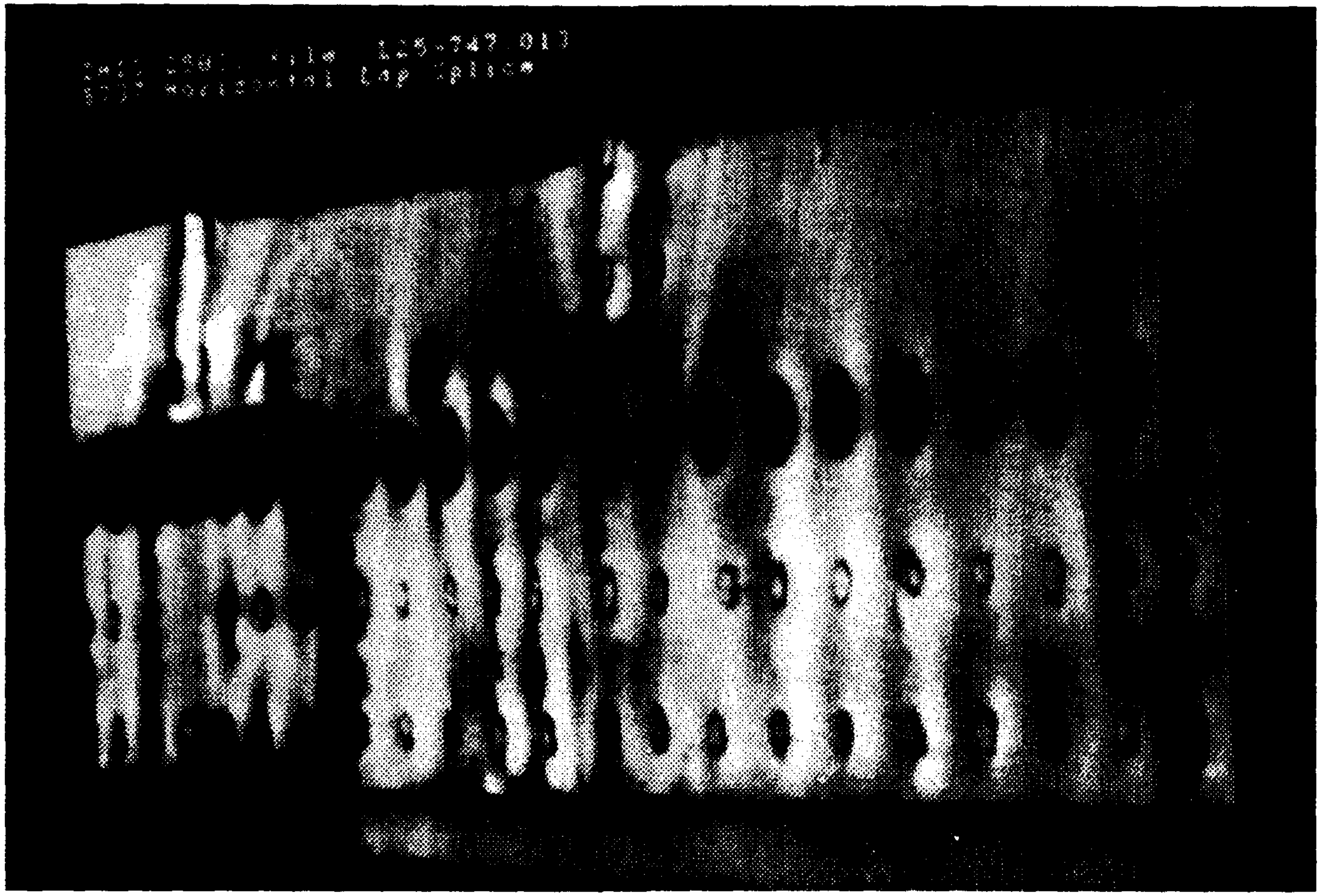


AANC, Sept 1993 - DAIS computer monitor

NRC·CNRC

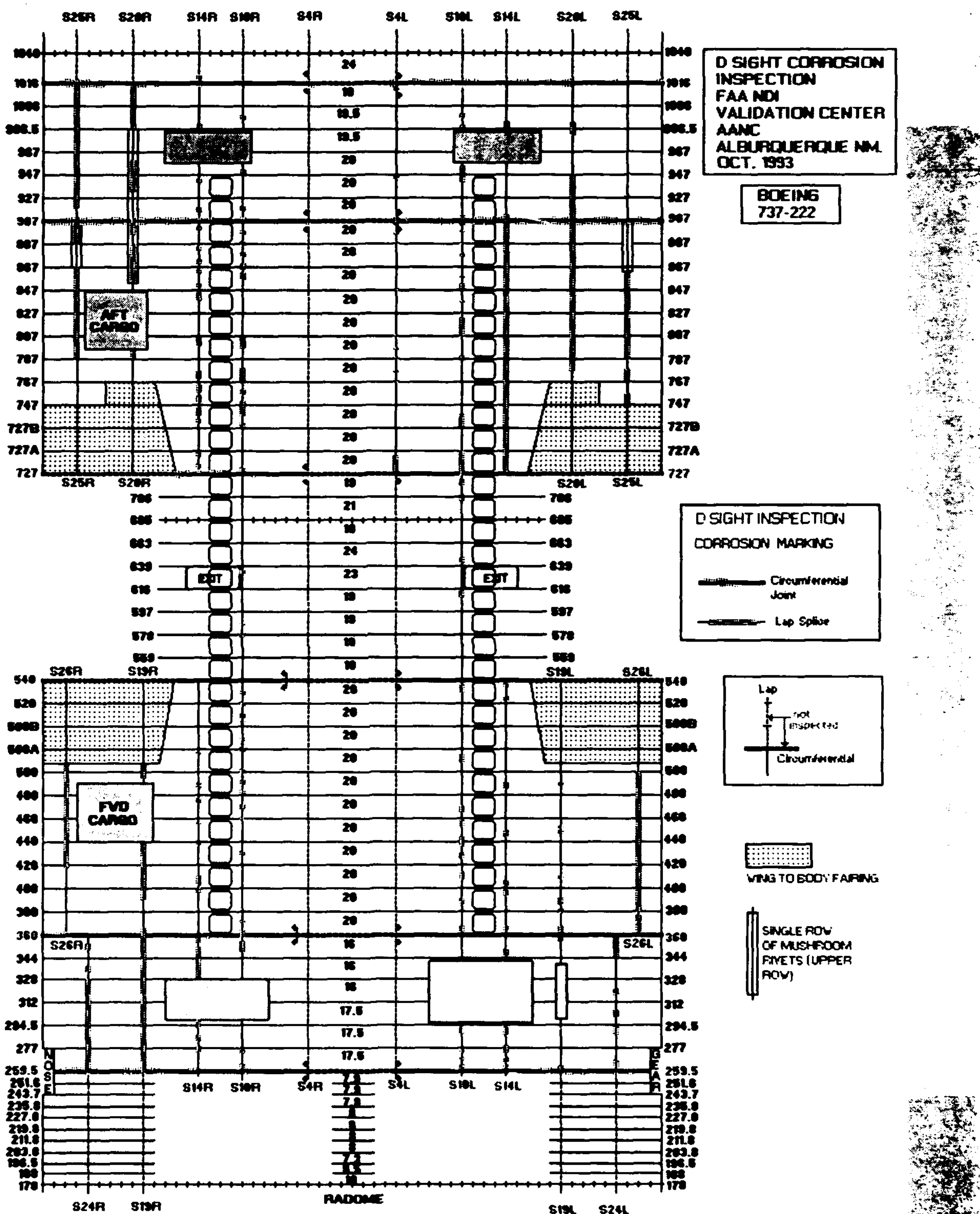
DIFFRACTO

D Sight for corrosion detection in aircraft structures



AANC, Sept 1993 - DAIS computer monitor

D Sight for corrosion detection in aircraft structures



NRC-CNRC

DIFFRACTO

D Sight for corrosion detection in aircraft structures

DAIS 250C at FAA Aging Aircraft nondestructive Validation Center

Longitudinal and Circumferential lap and butt splice inspection for corrosion of B 737-222 from BS 259.5 to BS 1016.

Inspection time:	11 man-hours (2 men 5.5 hours)
Analysis and report:	25 man-hours
Total time:	36 man-hours

Time required according to SB's: 278 man-hours

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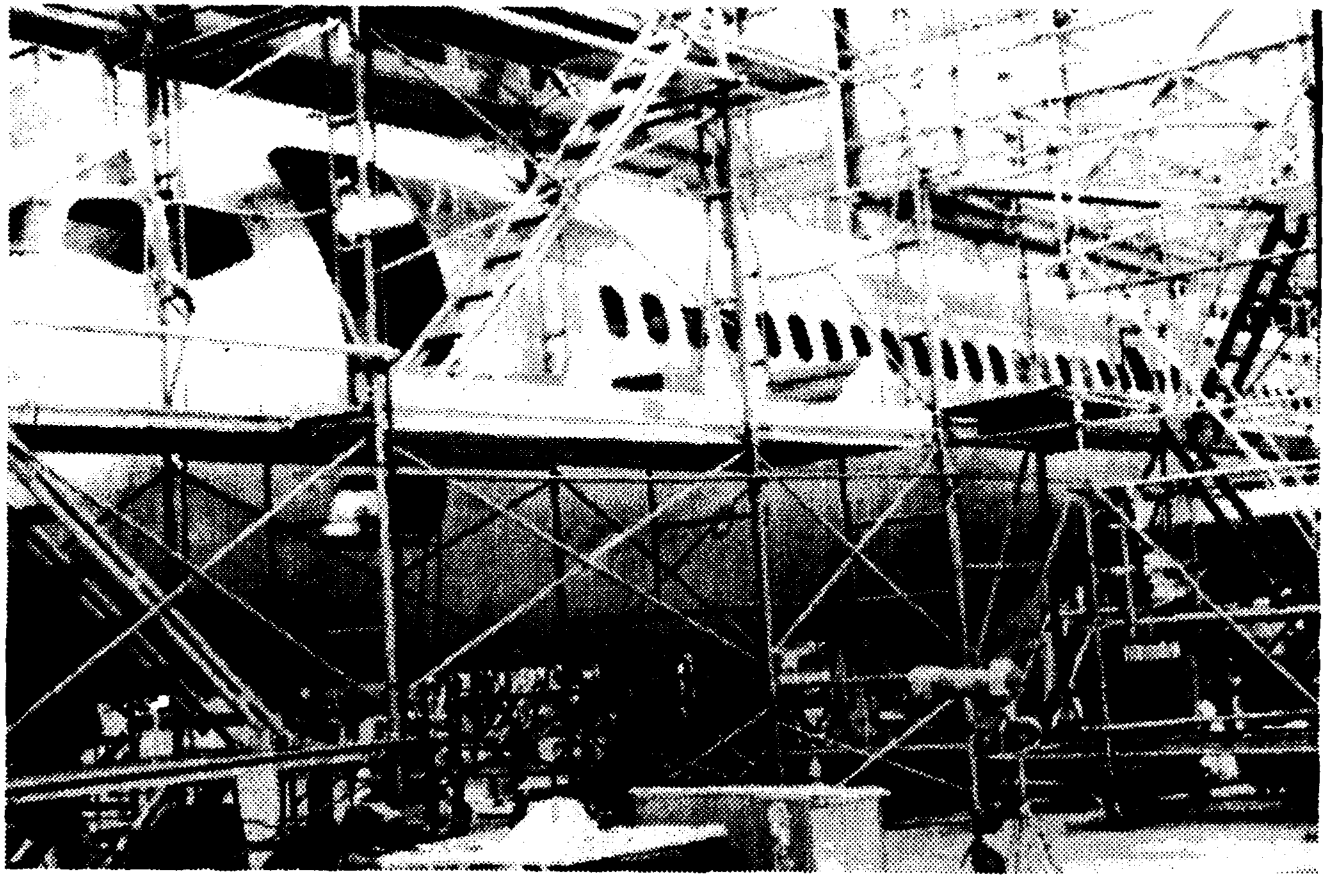
DIFFRACTO

D Sight for corrosion detection in aircraft structures



Air Canada - DC9 during D2 check

NRC·CNRC DIFFRACTO

D Sight for corrosion detection in aircraft structures

Air Canada - A320 during C check

D Sight for corrosion detection in aircraft structures

Conclusions

Demonstrated D Sight for corrosion in lap joints

Large specimen library created

Accelerated corrosion process developed

Breadboard DAIS tested in the field

Initial corrosion modeling performed

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D Sight for corrosion detection in aircraft structures

Future Work

Prototype DAIS designed and built

Enhanced D Sight image analysis

Continue accelerated corrosion

Simulate D Sight images
for DAIS calibration and training

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Adhesively Bonded and Composite Structures
(NAARP-NDI 3)
RP 199

FAA Center for Aviation and Systems Reliability

Project:	**Techniques for Flaw Detection**
Task:	**Laser-Based Ultrasonics**
Principal Investigator:	**J. D. Achenbach**
FAA Sponsor:	**Richard Yarges**
FAA Technical Monitor:	**Dave Galella**
Industrial Contacts:	**McDonnell Douglas** **UltraOptec**

Adhesively Bonded and Composite Structures
(NAARP-NDI 3)
RP 199

FAA Center for Aviation and Systems Reliability

Task: Laser-Based Ultrasonics

Objective: To exploit the advantages of laser-based ultrasonics for NDE of aircraft structures:

- Non Contact
- Point Generation and Detection
- Wide Frequency-Band Measurements
- Curved Surface Applicability
- Absolute Displacement Calibration
- Both Broad-Band and Narrow-Band Signal Generation
- Easy Scanning
- Remote Application by Use of Fiber Optics

Deliverables: A compact prototype fiberized system for laser-based ultrasonic inspection of aircraft structures

Studies of applications

Adhesively Bonded and Composite Structures
(NAARP-NDI 3)
RP 199

FAA Center for Aviation and Systems Reliability

Task: Laser-Based Ultrasonics

Accomplishments to-date:

- Developed dual-probe laser interferometer
- Developed new technique for narrow-band ultrasonic signal generation
- Laboratory results for crack detection and size determination

LASER-BASED ULTRASONICS

Principal Investigator:	J. D. Achenbach
Graduate Research Assistant:	Jin Huang
Technical Monitor:	Dave Galella

OBJECTIVES

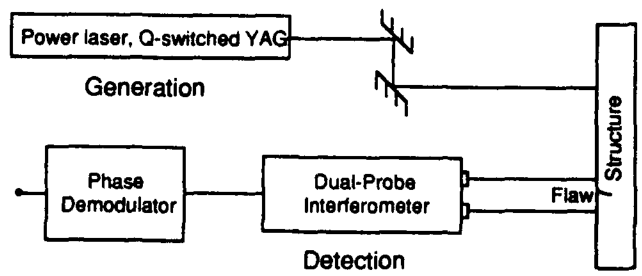
To exploit the advantages of laser-based ultrasonics for NDE of aircraft structures:

- **Non Contact**
- **Point Generation and Detection**
- **Wide Frequency-Band Measurements**
- **Curved Surface Applicability**
- **Absolute Displacement Calibration**
- **Both Broad Band and Narrow Band Signal Generation**
- **Easy Scanning**
- **Remote Application by Use of Fiber Optics**

The technique uses a laser or a transducer to excite ultrasound and a dual-probe laser interferometer for the measurement of ultrasonic signals.

LASER-BASED ULTRASONICS FOR QNDE

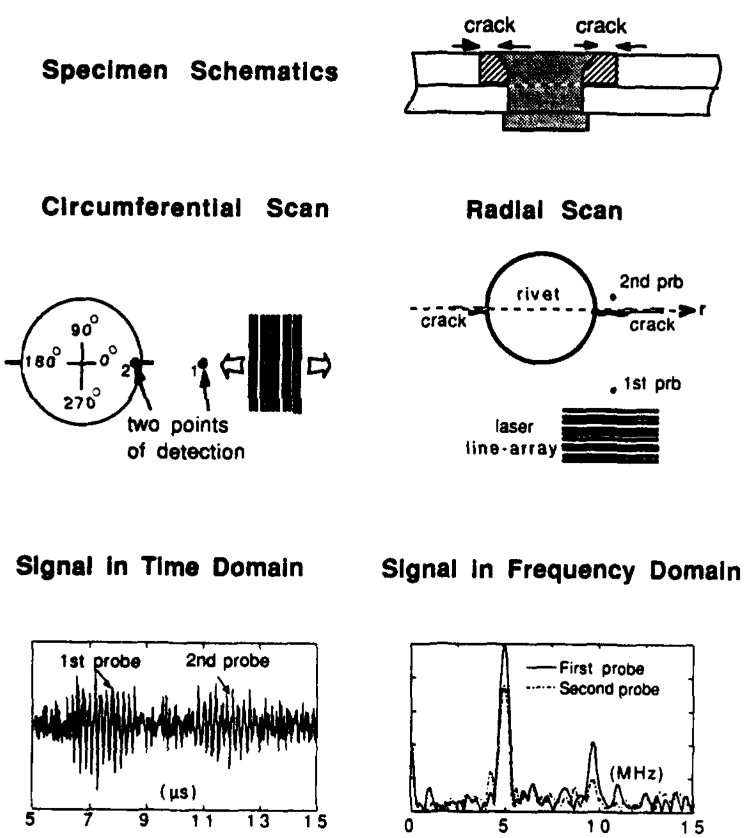
Schematic:



Applications Implemented:

- **Characterization of Surface Roughness**
- **Evaluate Fatigue Damage**
- **Determine Material Anisotropy**
- **Measure Thin Film Elastic Constants**
- **Detect Cracks in Fuselage Panel**
- **Fiber Guided Remote Crack Detection**

APPLICATION OF NARROW BAND SIGNAL GENERATION AND DUAL-PROBE DETECTION TO RIVET CRACK INSPECTION



Approach

1. Develop a dual-probe laser interferometer.
   Completed. The same sensitivity at both detecting points has been demonstrated.

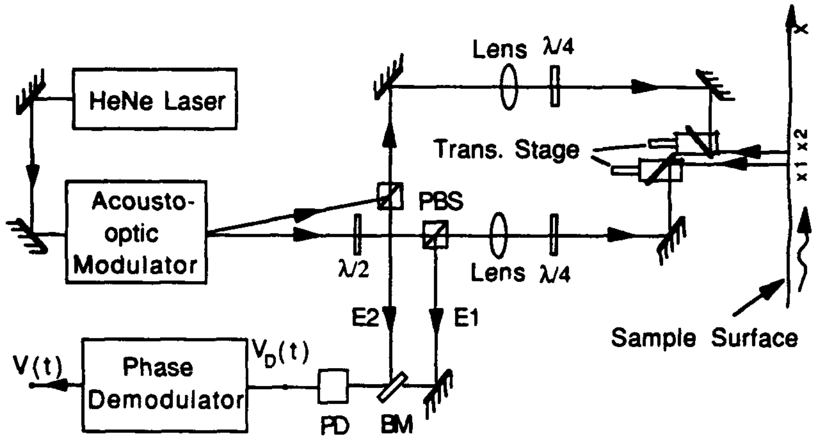
2. Develop a technique for improved narrow-band ultrasonic signal generation by the use of a line-focused laser.
   Completed. A tone-burst signal has been generated by the use of an optical diffraction grating and a lens system. The lens system provides controllable center frequency by adjustment of the width and spacing of the lines of laser illumination in the array.

3. A hybrid system using transducer generation but laser detection has also been used.

4. To improve the robustness of the laser-based ultrasonic system, fiber optics is being used to guide the laser beams to and from the structure that is being inspected.
   In progress.

DETECTION BY A DUAL-PROBE LASER INTERFEROMETER

Principle of the Dual-Probe Interferometer



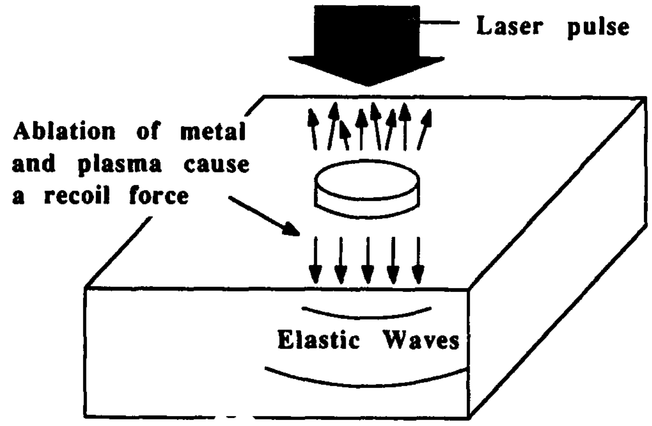
$$E_1=R_1\cos\{2\pi ft+(4\pi/\lambda)v(t,x_1)+\theta_1(t)\}$$

$$E_2=R_2\cos\{2\pi ft+2\pi f_Bt+(4\pi/\lambda)v(t,x_2)+\theta_2(t)\}$$

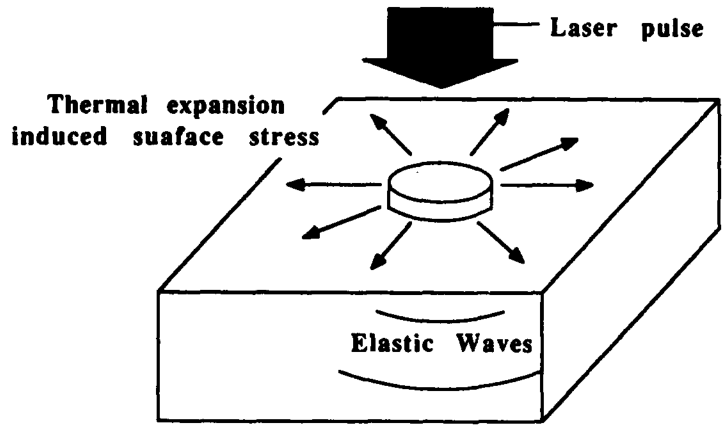
$$V_D(t)\propto 2R_1R_2\cos\{2\pi f_Bt-(4\pi/\lambda)[v(t,x_1)-v(t,x_2)] +[\theta_1(t)-\theta_2(t)]\}$$

$$V(t)=C\{v(t,x_1)-v(t,x_2)\}$$

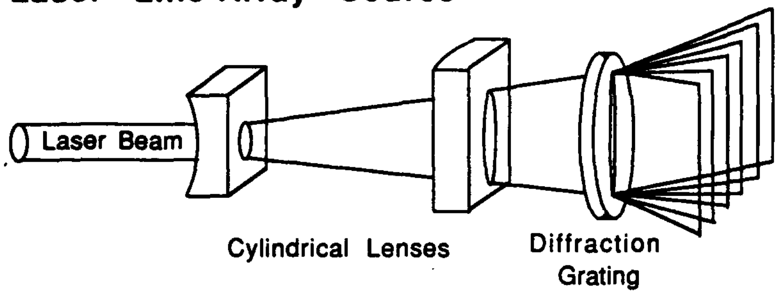
GENERATION IN ABLATION REGION



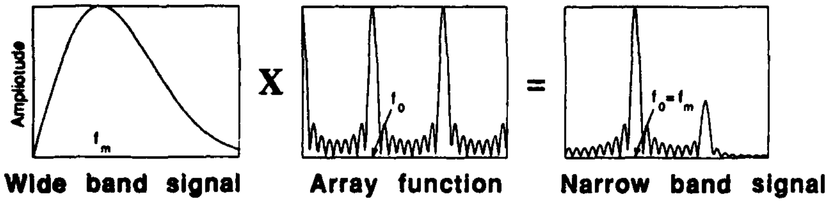
GENERATION IN THERMOELASTIC REGION



Laser Line-Array Source

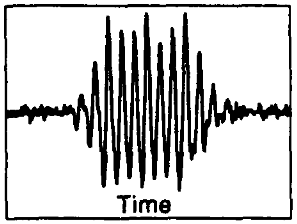


Principle of Narrow Band Signal Generation

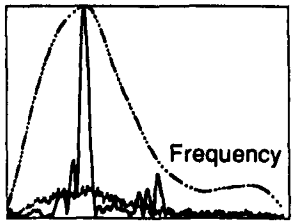


Optimum Generation Condition: $\delta = c/f_0$ & $d = \delta/\pi$

Narrow Band Signal

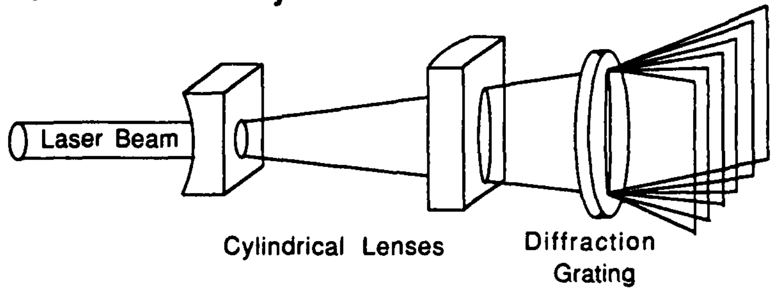


Optimized tone-burst

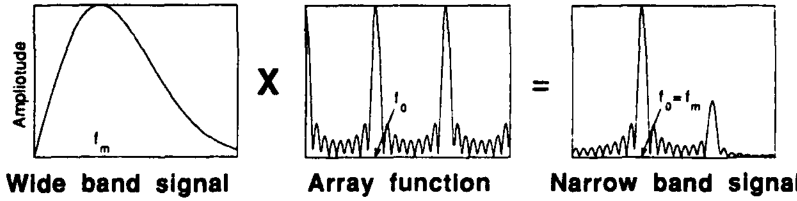


Spectrum of the optimized tone burst

Laser Line-Array Source



Principle of Narrow Band Signal Generation



Spectrum for Line-Array Generation:

$$G(f) = NH(f)S(f)$$

where

$$S(f) = \frac{\sin(\pi N f \Delta t)}{N \sin(\pi f \Delta t)} \quad \& \quad H(f) \propto f e^{-\pi^2 d^2 f^2/4c}$$

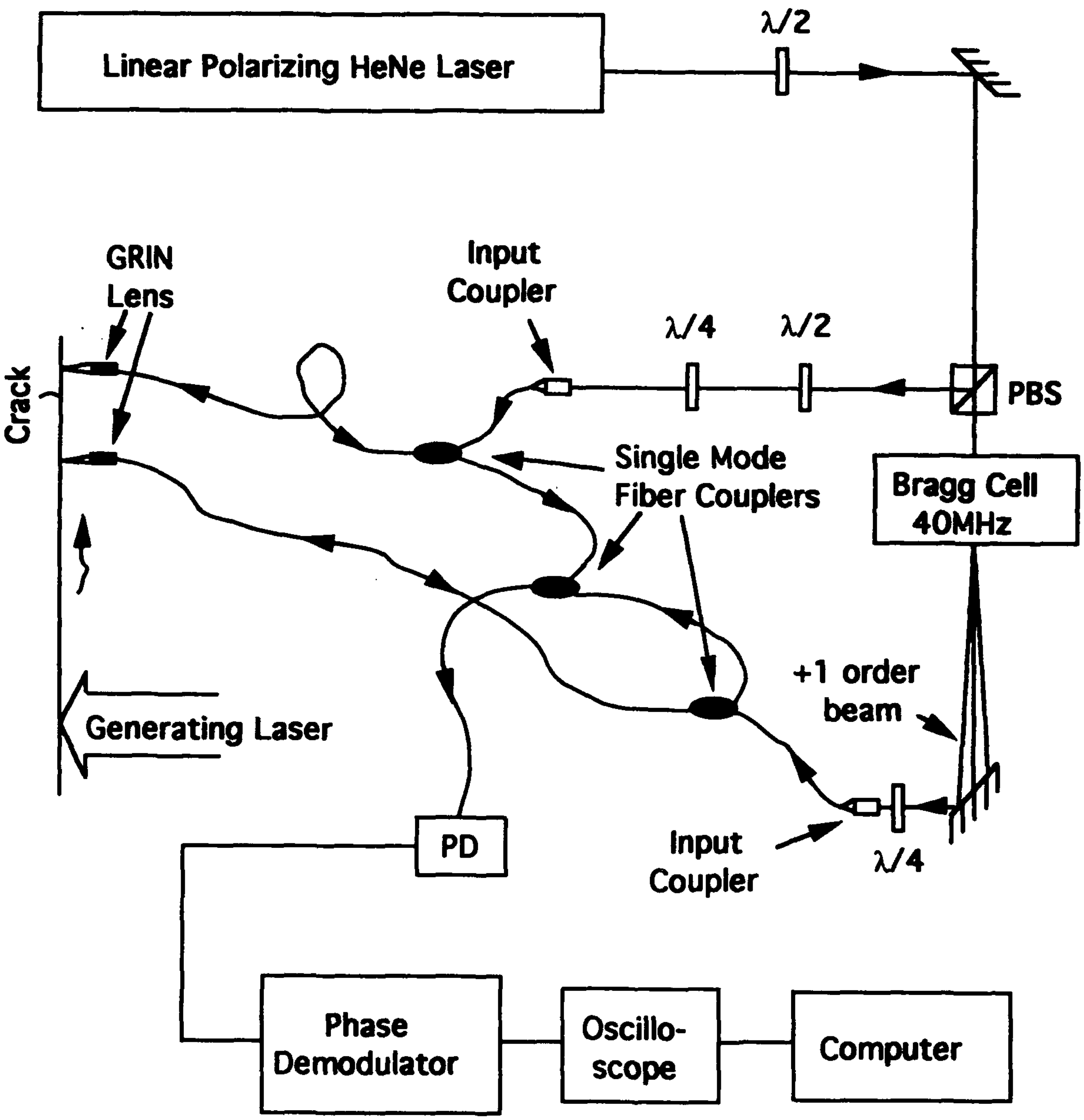
It can be shown

$$f_m = \frac{\sqrt{2}c}{\pi\delta} \quad \& \quad f_0 = \frac{c}{\delta}$$

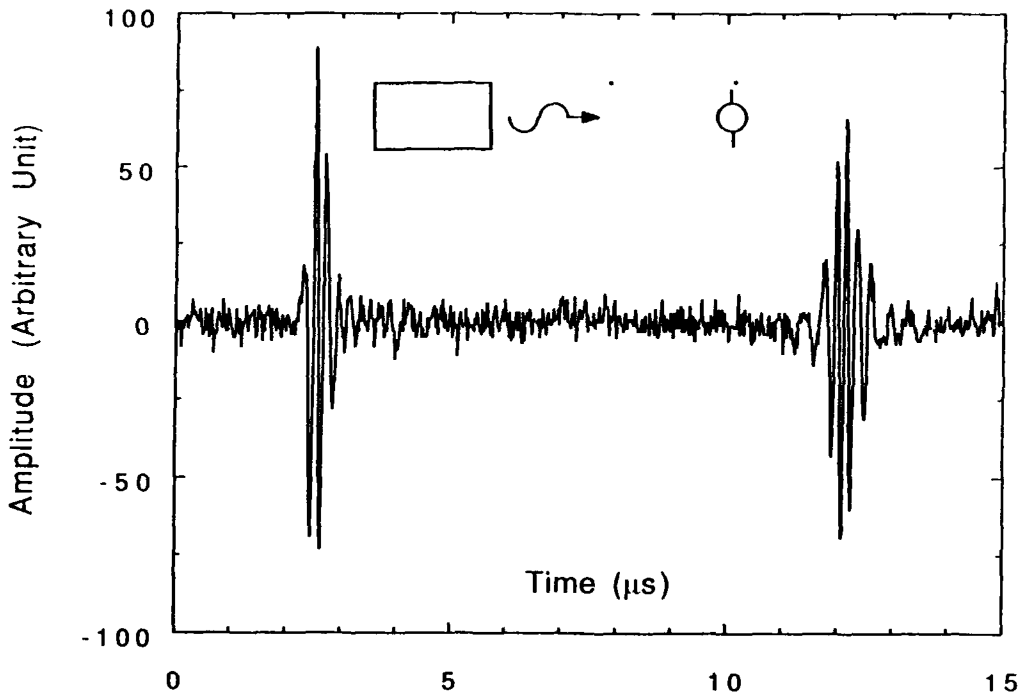
Optimum Generation Condition: $f_0 = f_m$

i.e. $\delta = c/f_0$ & $d = \delta/\pi$

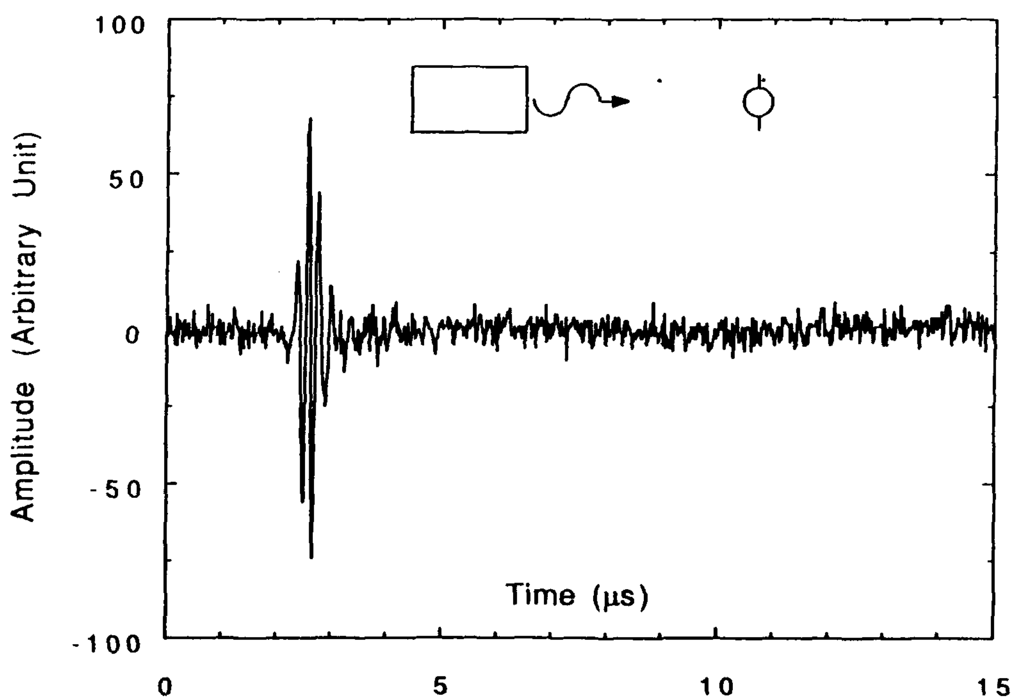
DIAGRAM OF THE DUAL-PROBE FIBER INTERFEROMETER



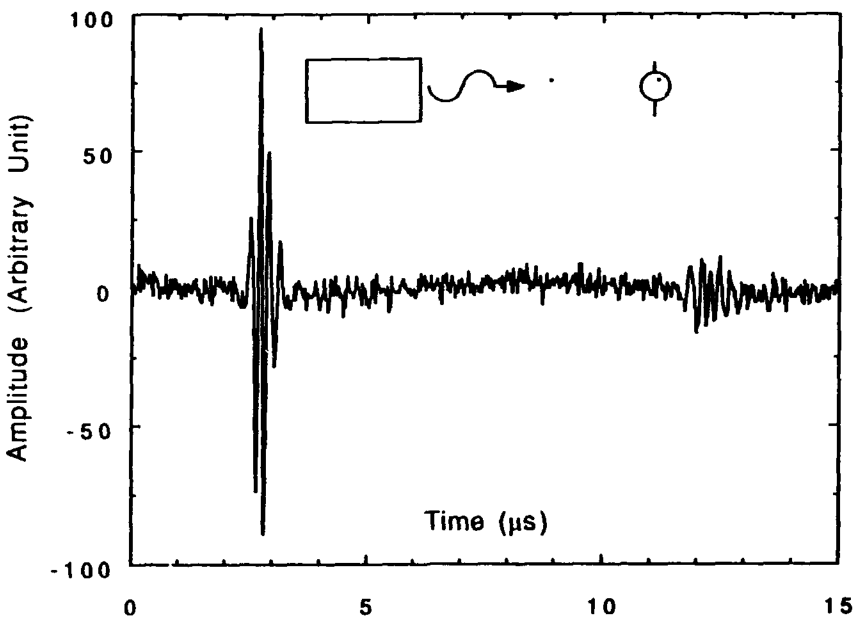
Crack Detection with Dual-Probe Fiber Interferometer



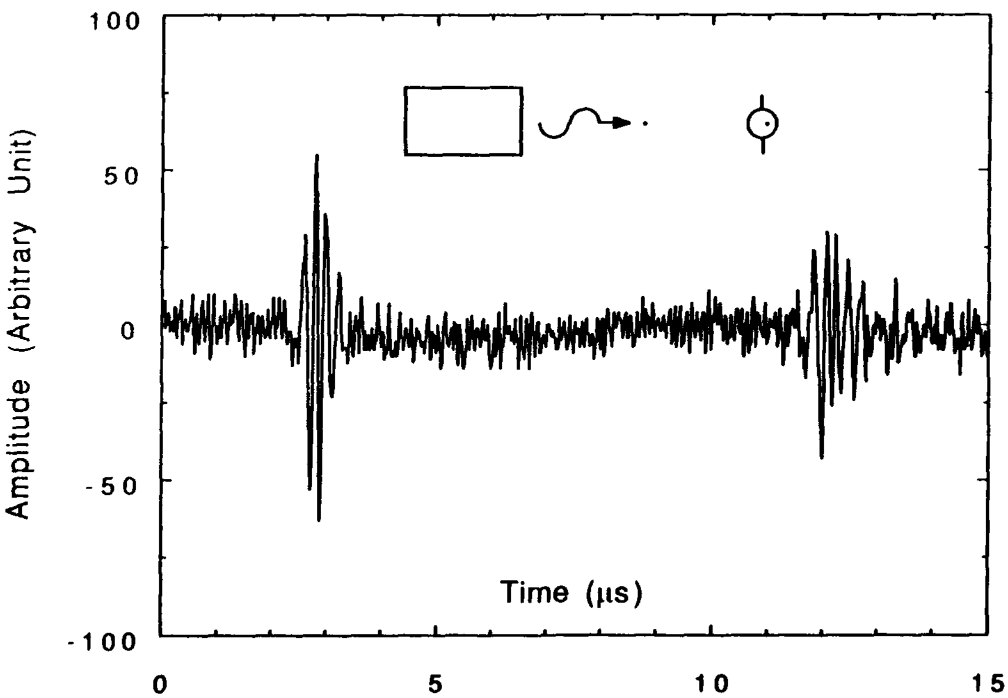
Crack Detection with Dual-Probe Fiber Interferometer



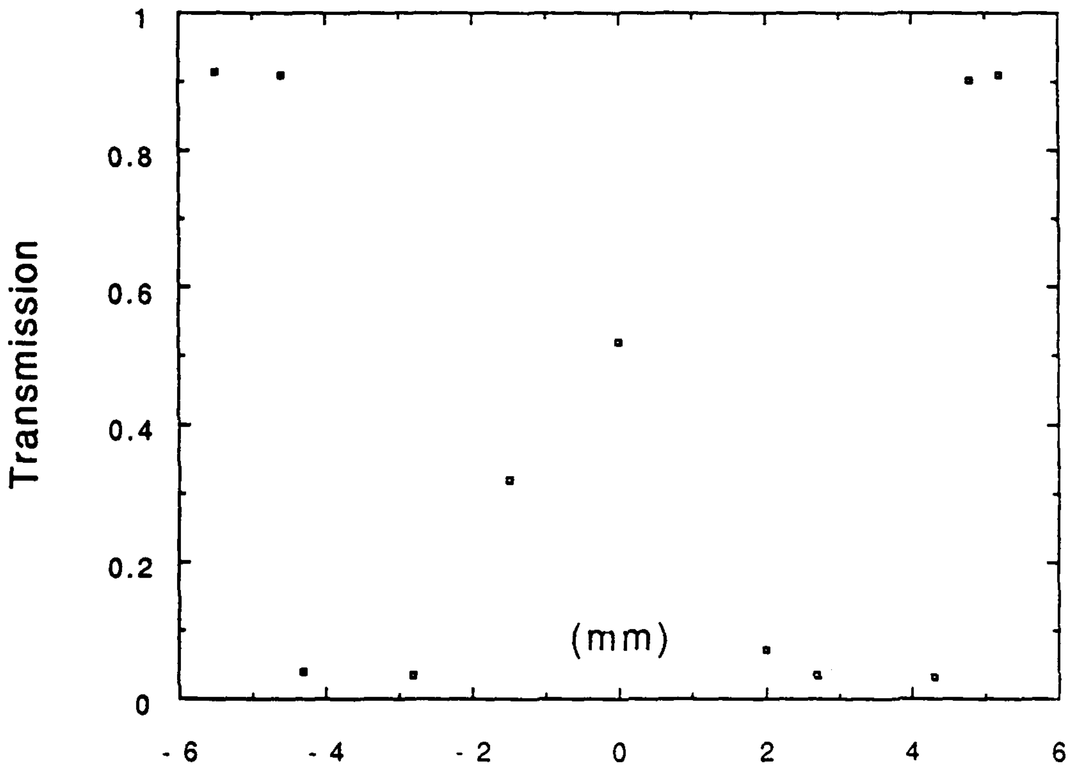
Crack Detection with Dual-Probe Fiber Interferometer

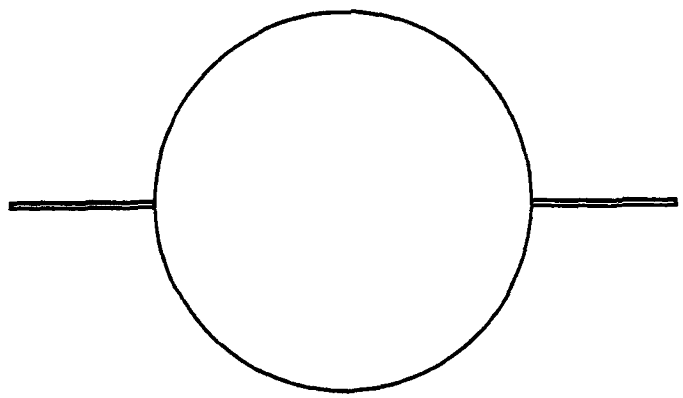


Crack Detection with Dual-Probe Fiber Interferometer

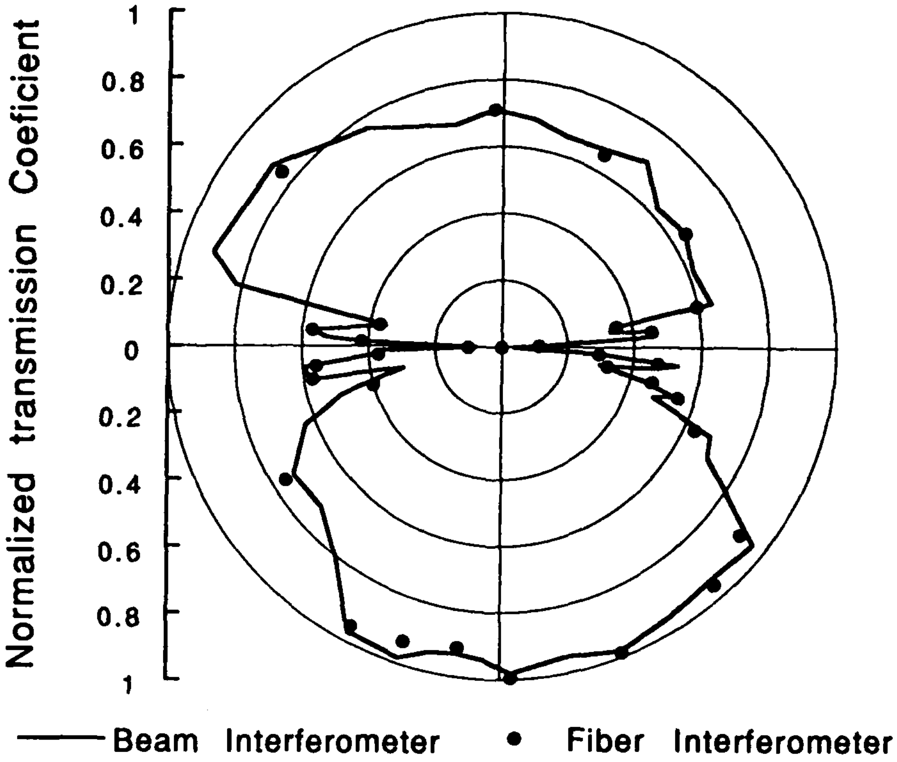


Rivet Crack Detection with Dual-Probe Fiber Interferometer Transducer Generation

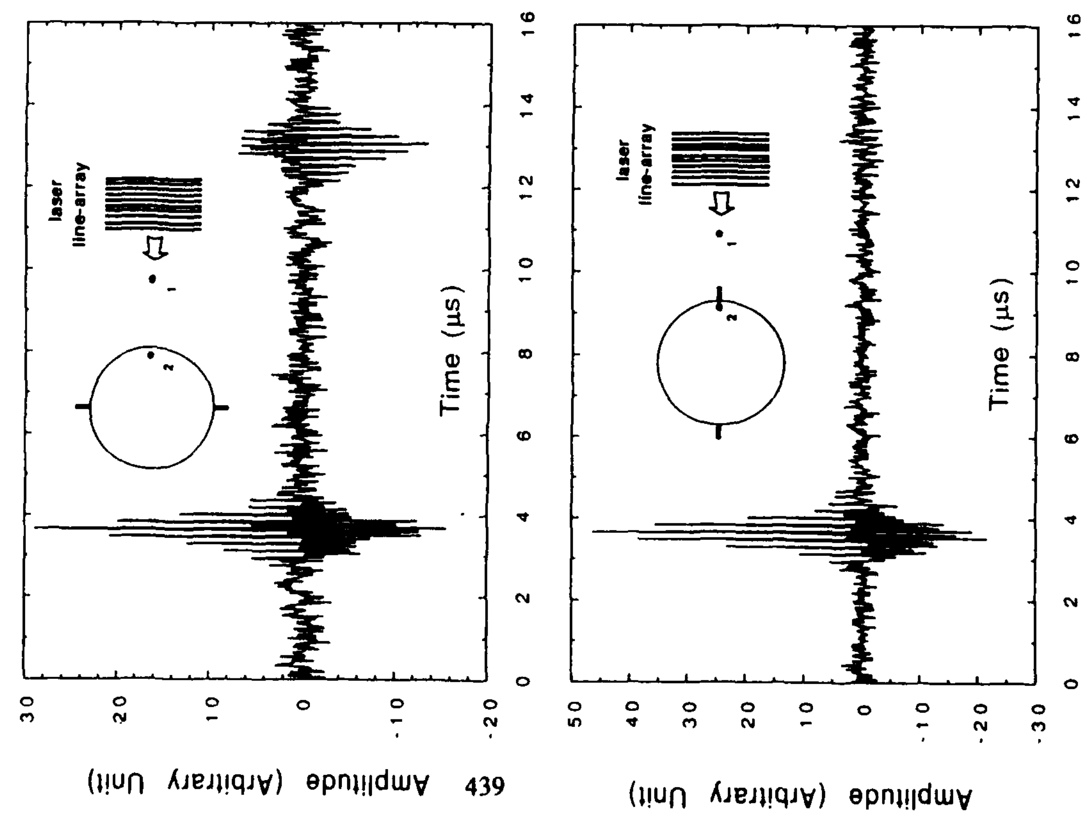




Circumferential Scan of a Rivet Head

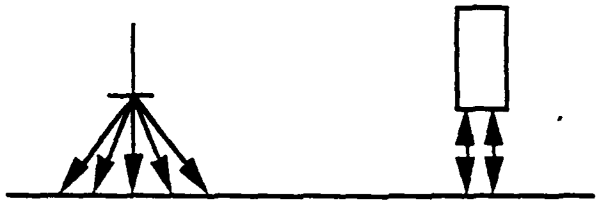


Dual-Probe Fiber Interferometer Detection with Laser Generated Narrow-Band Signal

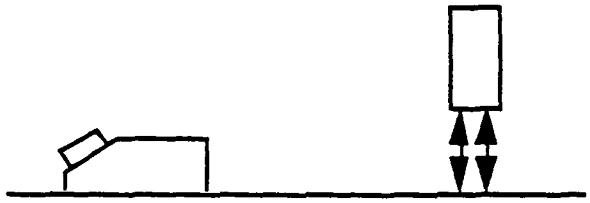


SUMMARY OF MODALITIES

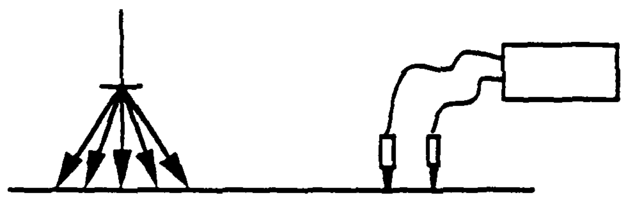
1. Laser-beam-in, Laser-beam interferometer out



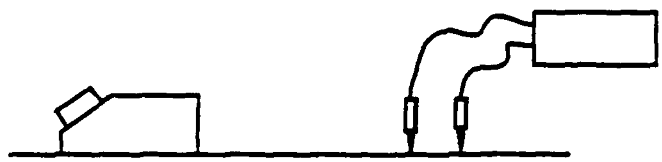
2. Transducer-in, Laser-beam interferometer out



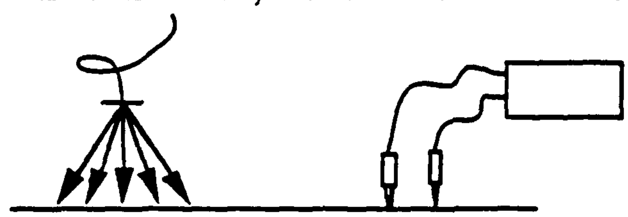
3. Laser-in, Fiberized interferometer out



4. Transducer-in, Fiberized interferometer out



5. Laser-fiberized-in, Fiberized interferometer out



Option 4 Most Robust & Low Cost

Adhesively Bonded and Composite Structures (NAARP-NDI 3) RP 199

FAA Center for Aviation and Systems Reliability

Task: Laser-Based Ultrasonics

Future Directions:

Investigate effects of paint

Create a compact fiberized system

Investigate applications to parts of complex shape

engine parts

composite materials

NDE Equipment
Research
RPI 199

FAA Center for Aviation Systems Reliability

Project:	Techniques for Flaw Detection
Task:	Self-Compensating Ultrasonic Technique
Principal Investigators:	Igor N. Komsky and Jan D. Achenbach
FAA Sponsor:	Richard Yarges
FAA Technical Monitor:	Dave Galella
Industrial Contacts:	Northwest Airlines McDonnell Douglas Corp. Panametrics Sonix Adaptronics Infometrics

NDE Equipment
Research
RPI 199

FAA Center for Aviation Systems Reliability

Task: Self-Compensating Ultrasonic Technique

Objective: To adapt self-compensating ultrasonic technique that has been developed at Northwestern University for detection and characterization of defects in aircraft structures.

Deliverables:

A prototype ultrasonic sensor with a self-compensating technique.

A computerized system for data acquisition and signal analysis.

An assessment of the range of applicability of the sensor/technique.

NDE Equipment
Research
RPI 199

FAA Center for Aviation Systems Reliability

Task: Self-Compensating Ultrasonic Technique

Accomplishments to date:

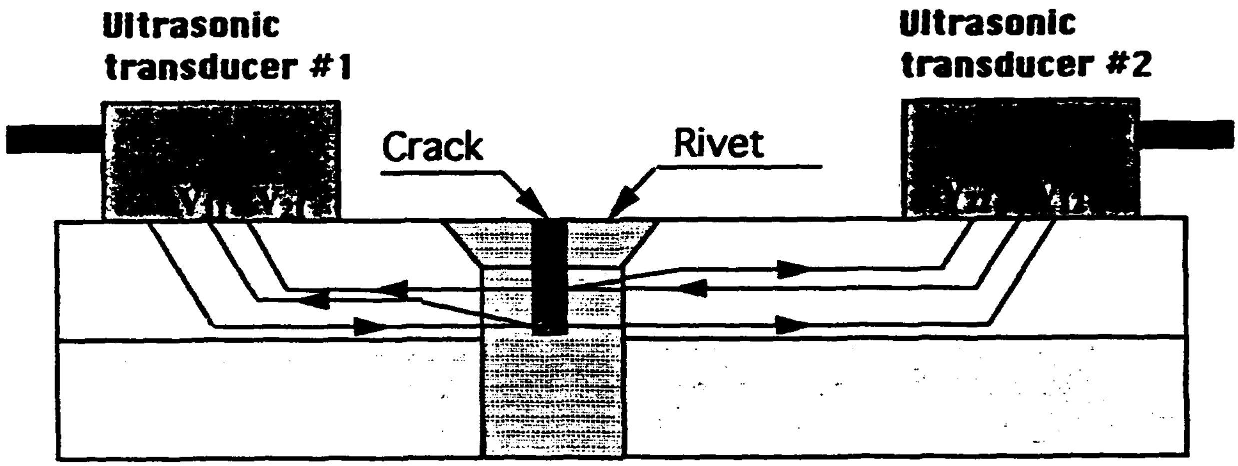
Prototype ultrasonic probe for second layer crack detection.

Self-Compensating Technique for size determination of cracks.

Computerized laboratory system for data acquisition and signal analysis.

SELF-COMPENSATING

ULTRASONIC TECHNIQUE



$$V_{11}=A_1 \cdot D_{10} \cdot R_C \cdot D_{01} \cdot S_1$$

$$V_{12}=A_1 \cdot D_{10} \cdot T_C \cdot D_{02} \cdot S_2$$

$$V_{22}=A_2 \cdot D_{20} \cdot R_C \cdot D_{02} \cdot S_2$$

$$V_{21}=A_2 \cdot D_{20} \cdot T_C \cdot D_{01} \cdot S_1$$

$$\left|\frac{V_{11} \cdot V_{22}}{V_{12} \cdot V_{21}}\right|^{1/2} = \left|\frac{R_C}{T_C}\right|$$

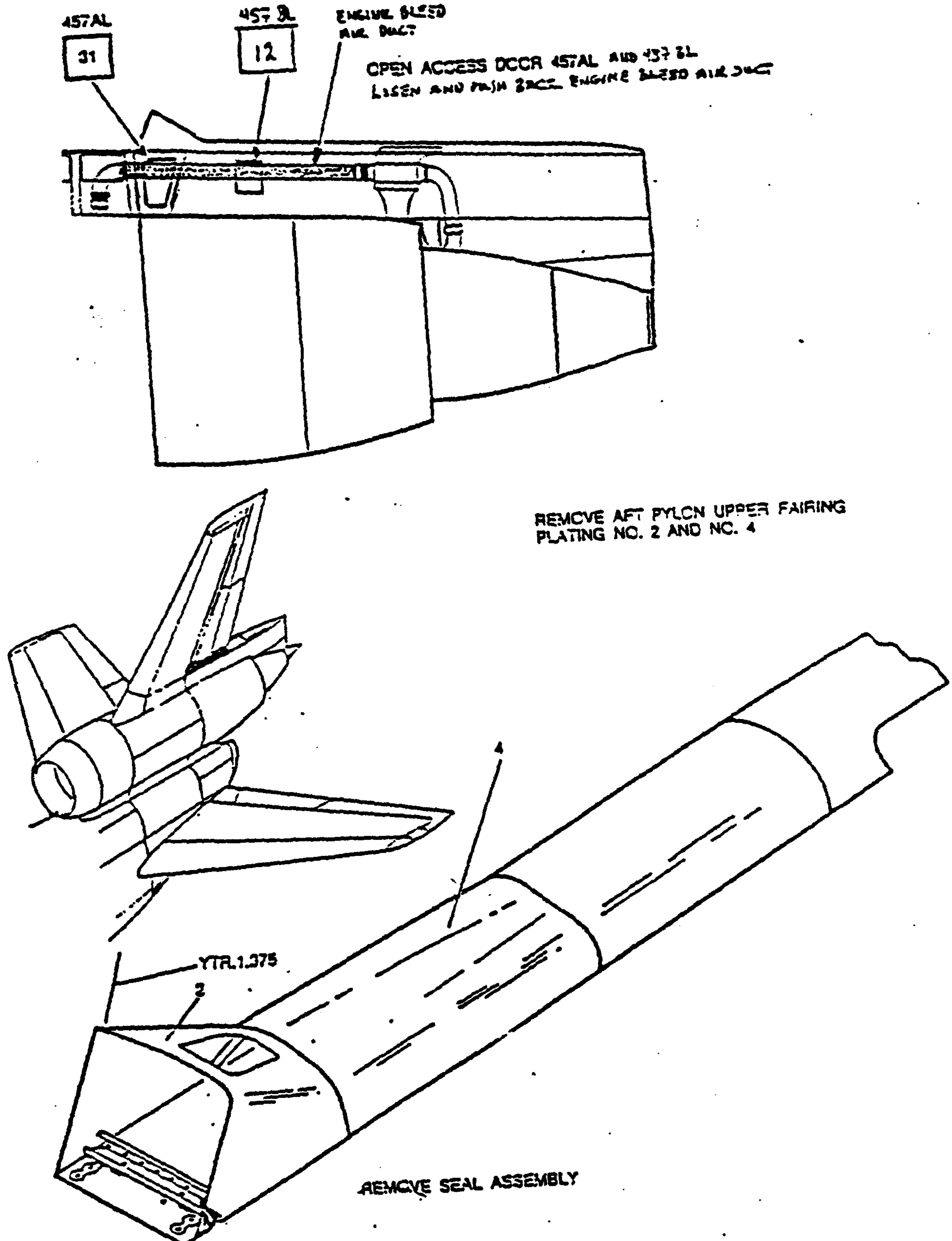
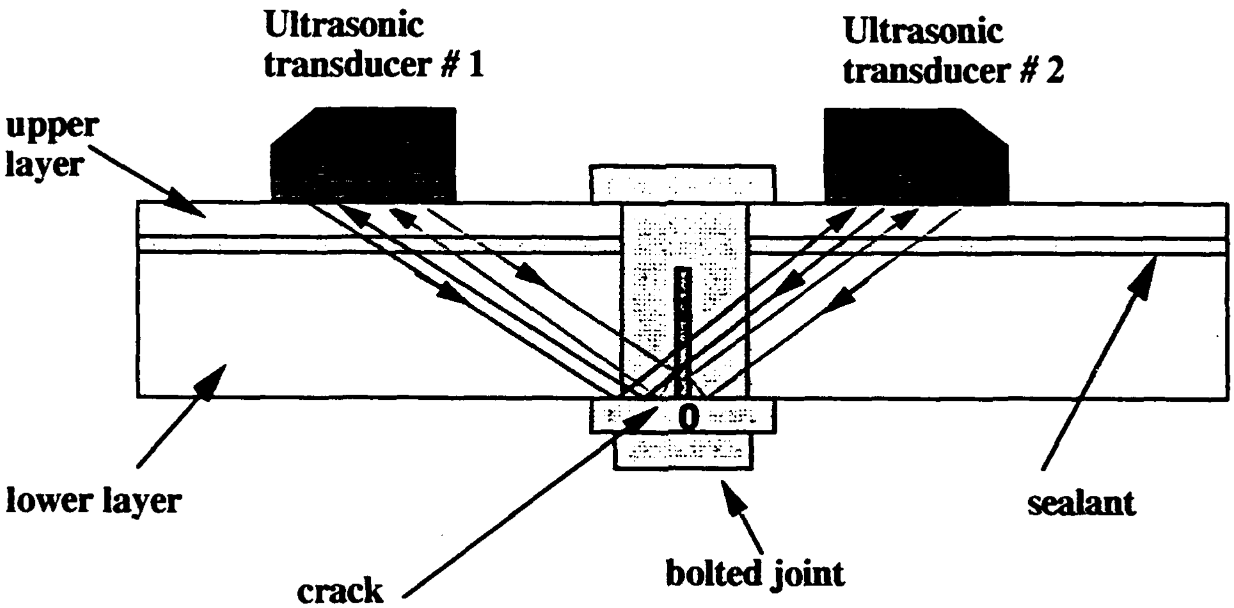


FIGURE 2. ACCESS

PSE 54.10.031/.032

DRAFT

Self-compensating technique for ultrasonic inspection of DC-10 spar-cap/strap connection



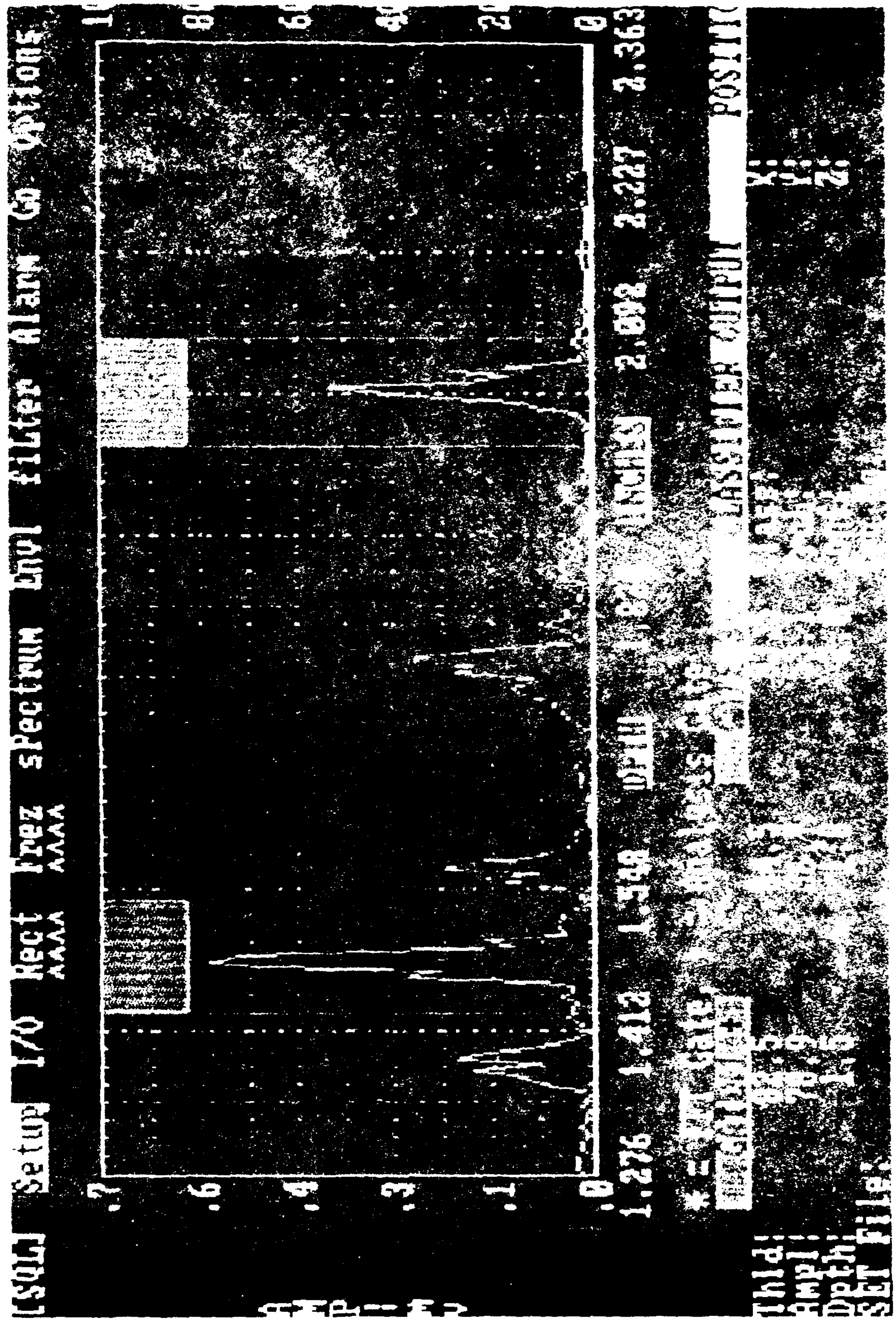
$$V_{11} = A_1 \cdot D_{10} \cdot R_{1C} \cdot D_{01} \cdot S_1$$

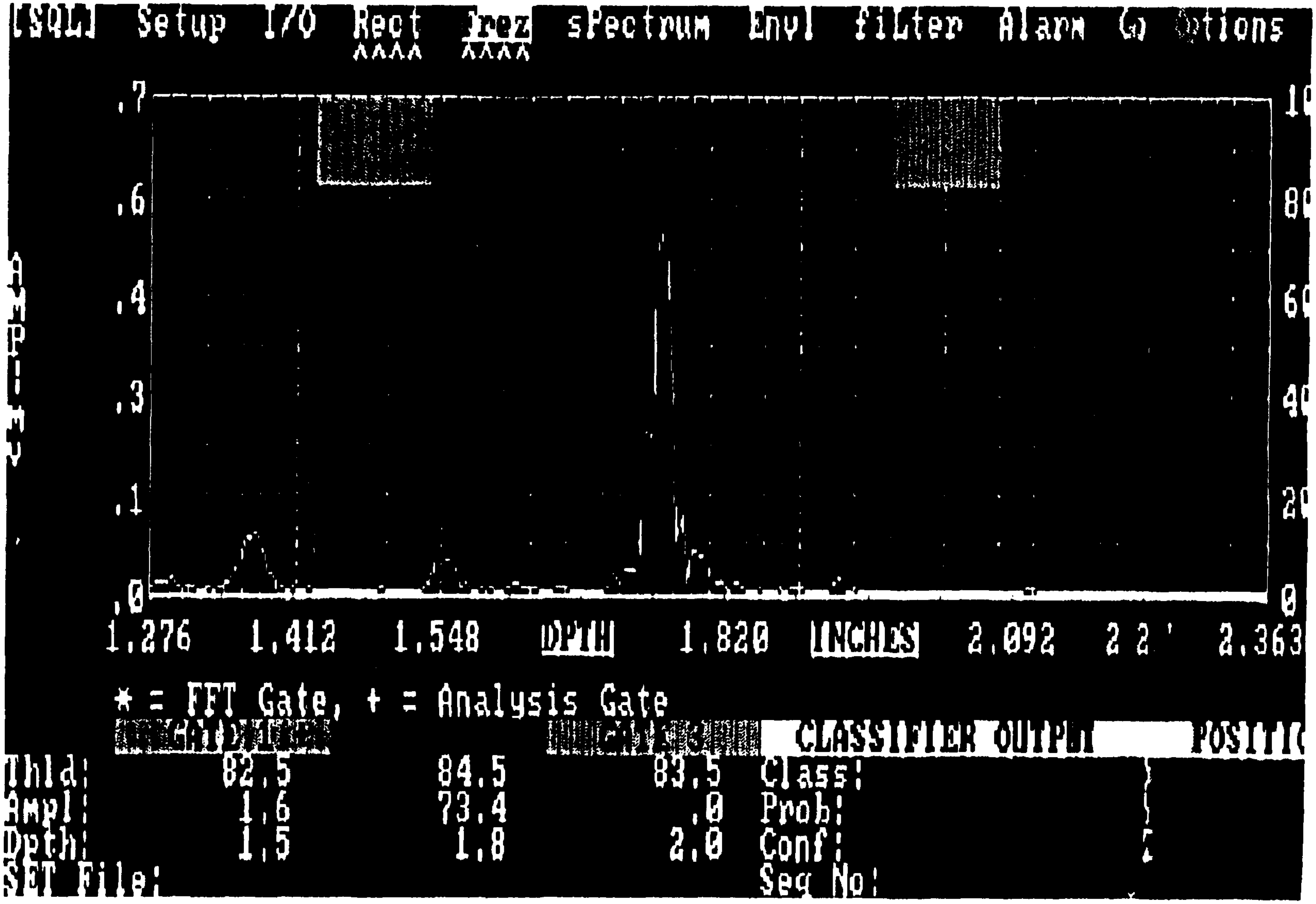
$$V_{12} = A_1 \cdot D_{10} \cdot T_{1C} \cdot D_{02} \cdot S_2$$

$$V_{22} = A_2 \cdot D_{20} \cdot R_{2C} \cdot D_{02} \cdot S_2$$

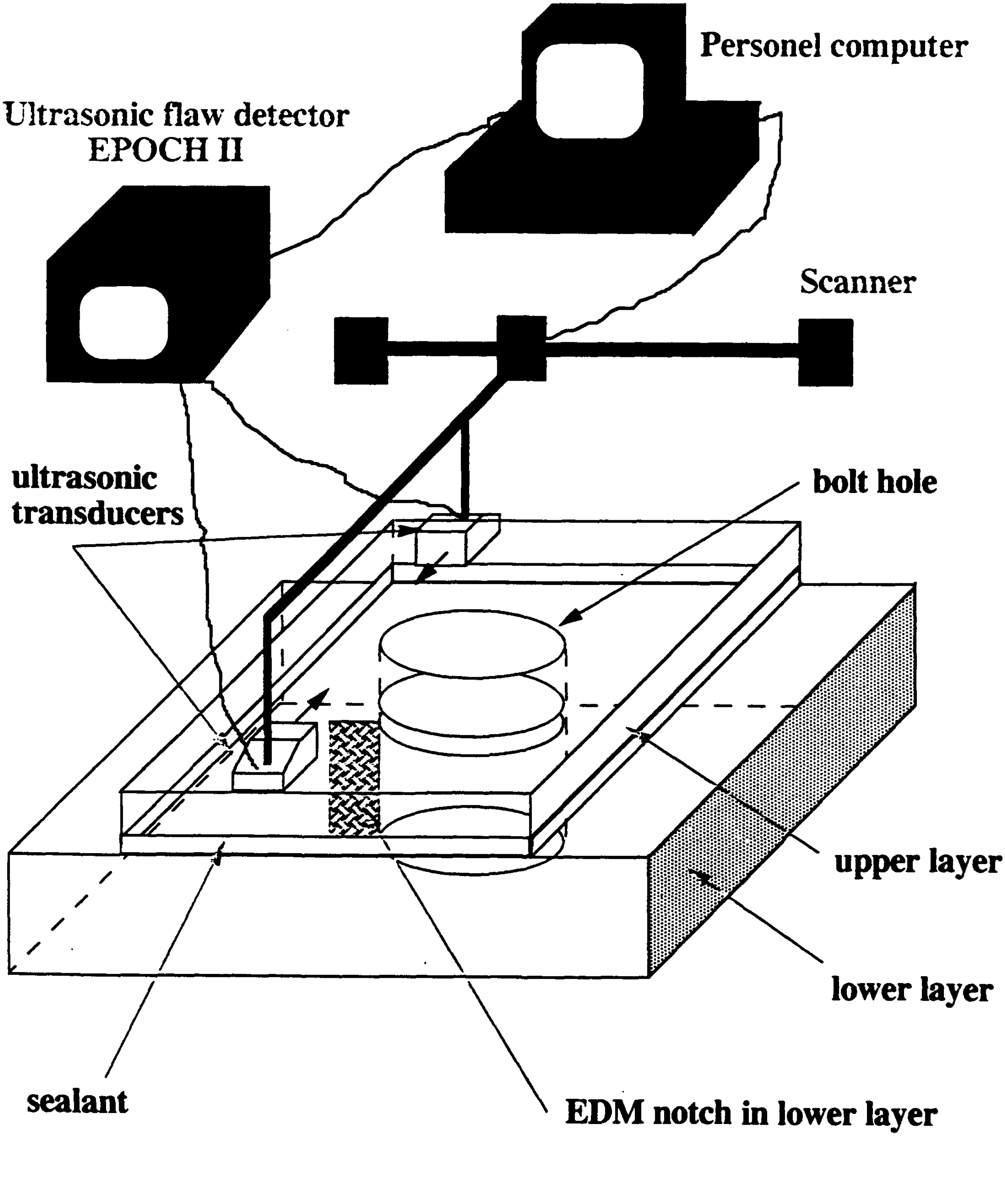
$$V_{21} = A_2 \cdot D_{20} \cdot T_{2C} \cdot D_{01} \cdot S_1$$

$$\left| \frac{V_{11} \cdot V_{22}}{V_{12} \cdot V_{21}} \right| = \left| \frac{R_{1C} \cdot R_{2C}}{T_{1C} \cdot T_{2C}} \right|$$

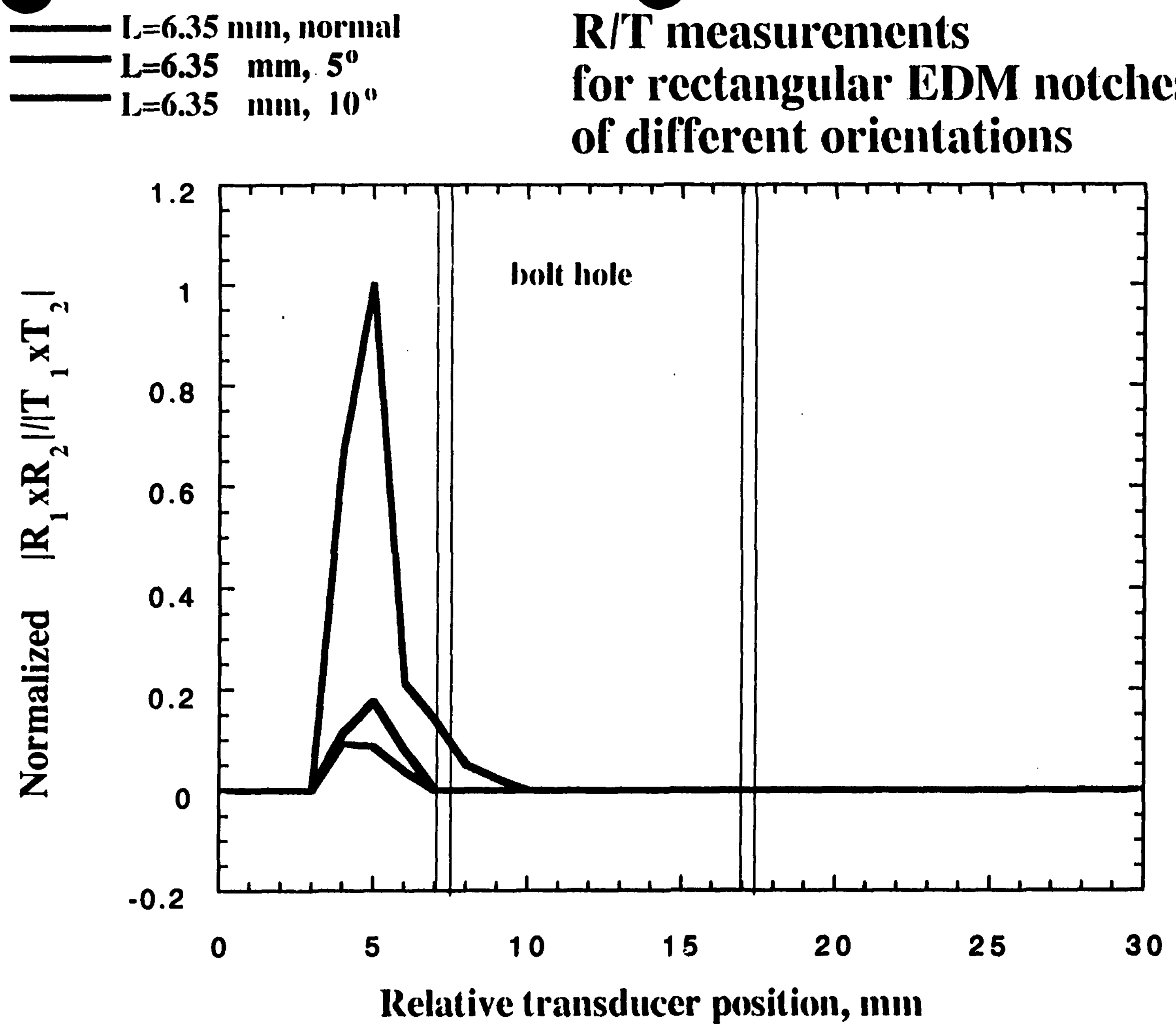

[SQL] Setup I/O Rect Frez sPectrum Envl Filter Alarm Go Options
1.276 1.412 1.548 2.092 2.227 2.363
INCHES
LASTFILTER OUTPUT
Thld:
Ampl:
Dpth:
SET File:


[SQL] Setup I/O Rect freq sPectrum Envl fiLter Alarm G) Options
.7
.6
.4
.3
.1
.0
1.276 1.412 1.548 DPTH 1.820 INCHES 2.092 2.363
* = FFT Gate, + = Analysis Gate
CLASSIFIER OUTPUT
Thld: 82.5 84.5 83.5
Ampl: 1.6 73.4 .0
Dpth: 1.5 1.8 2.0
SET File:
Class:
Prob:
Conf:
Seq No:

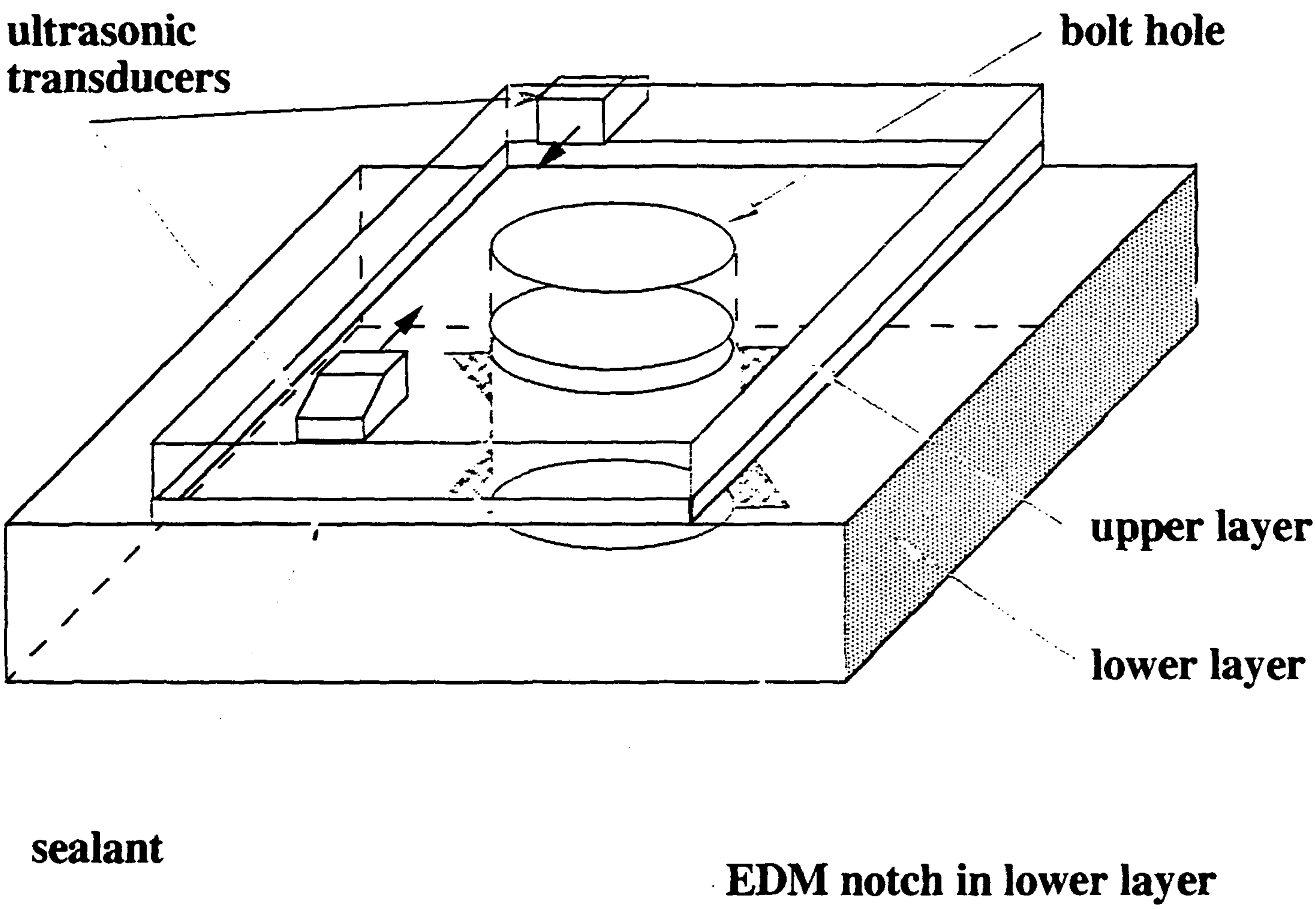
Experimental configuration for ultrasonic inspection of DC-10 spar-cap/strap connection with rectangular EDM notch

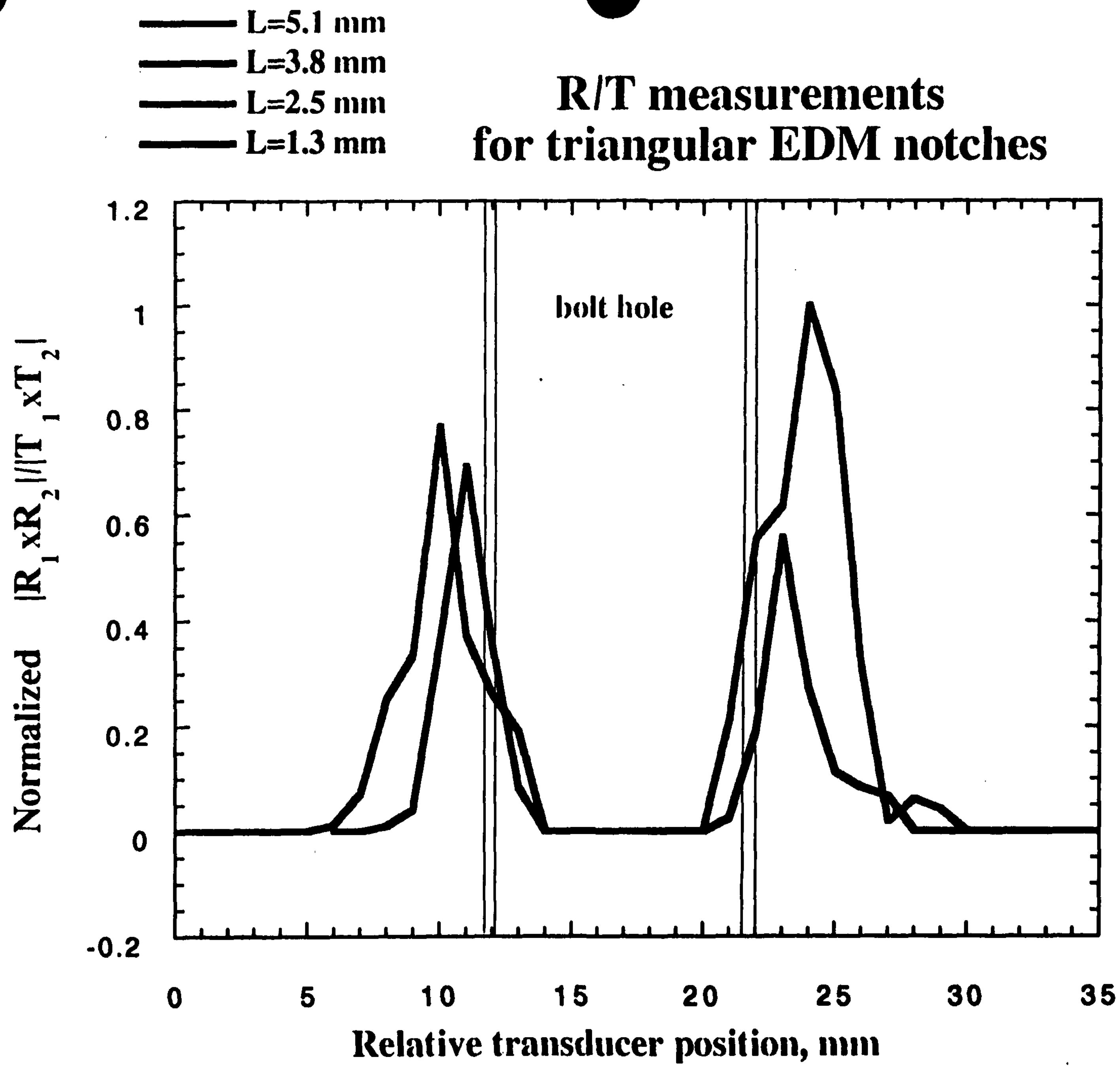


R/T measurements for rectangular EDM notches of different orientations

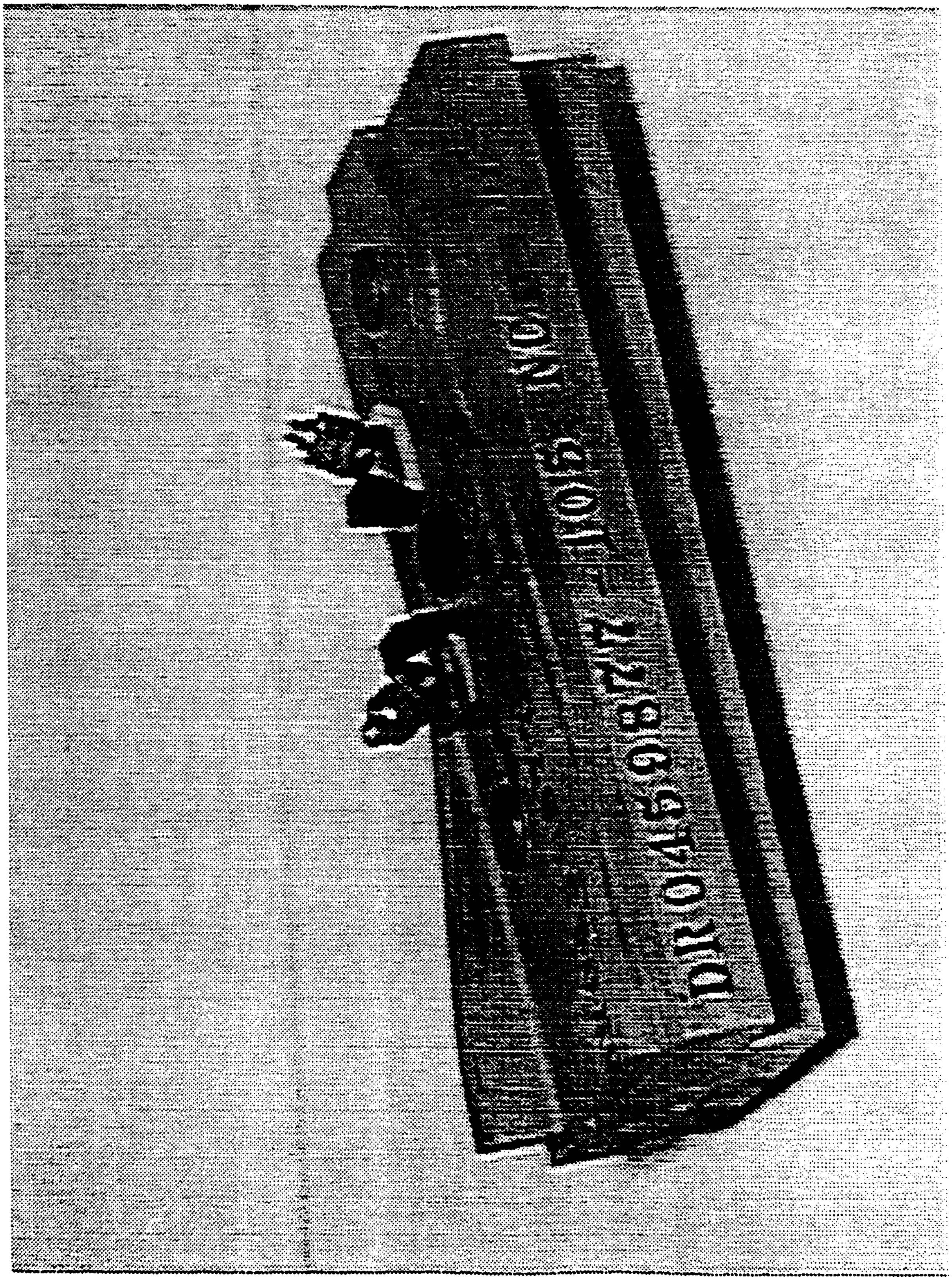


Model of DC-10 spar-cap/strap connection with triangular EDM notches

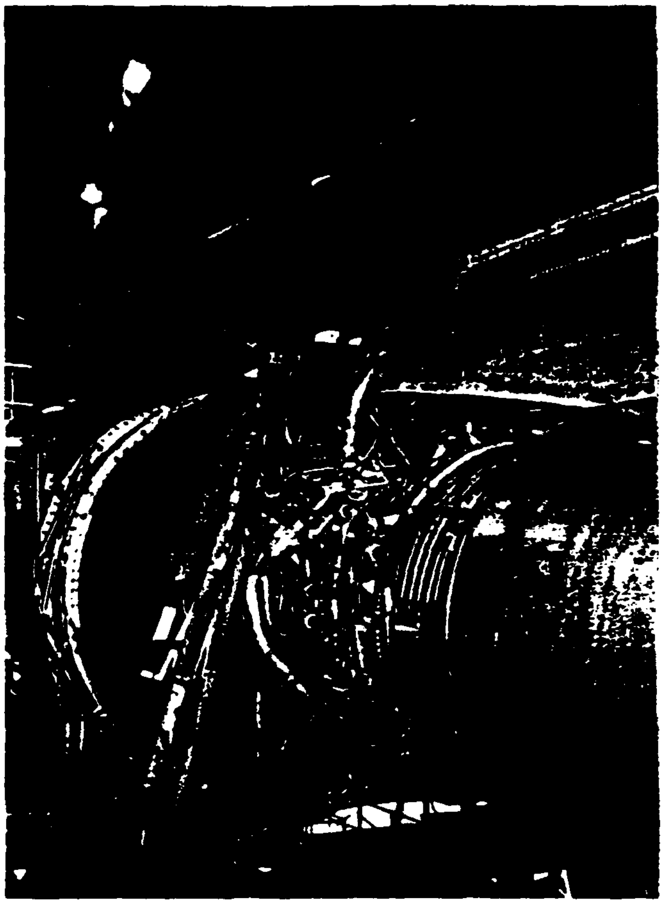


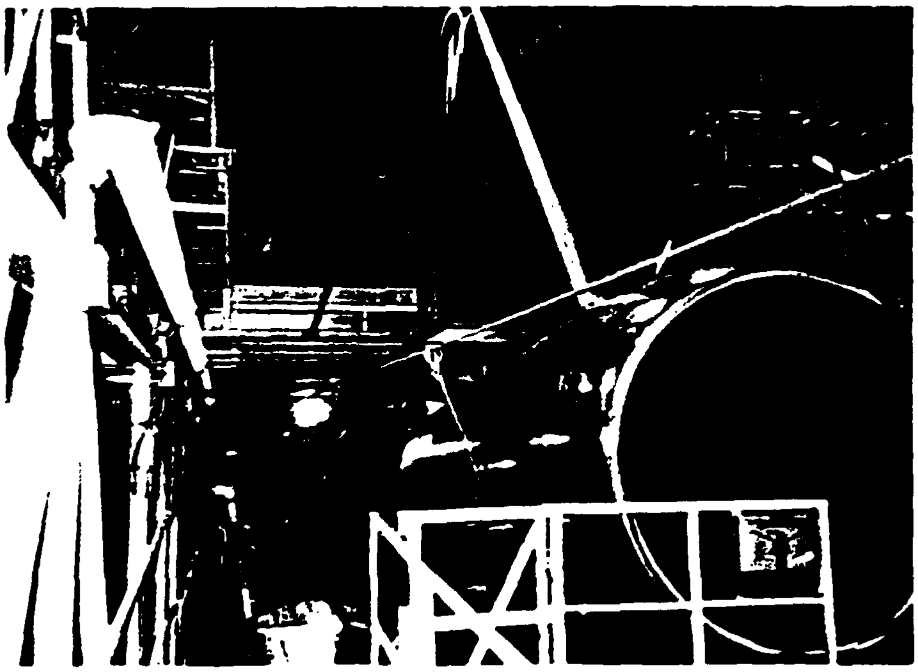


L=5.1 mm
L=3.8 mm
L=2.5 mm
L=1.3 mm
R/T measurements
for triangular EDM notches
bolt hole
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
0
5
10
15
20
25
30
35
Normalized $|R_1 x R_2|/|T_1 x T_2|$
Relative transducer position, mm



Site for ultrasonic inspection of DC-10 spar-cap/strap connection





Ultrasonic inspection of DC-10 spar-cap/strap connection

Ultrasonic inspection of DC-10 spar-cap/strap connection

Igor Komsky
Northwestern University,
Evanston, IL

TECHNOLOGY ↓ TRANSFER

Bill Jappe
McDonnell Douglas Corp.
Long Beach, CA

NDE Equipment
Research
RPI 199

FAA Center for Aviation Systems Reliability

Task: Self-Compensating Ultrasonic Technique

Future Directions:

Crack Detection

Development of the transducer fixture for manual scanning.
Development of the calibration specimen.
Development of technological procedure for ultrasonic inspection.

Crack Characterization

Development of a computerized system for data acquisition and signal classification using

Flaw library
-specimens with artificial flaws (EDM notches)
-specimens with implanted fatigue cracks.

Techniques for Flaw Detection RPI 199

FAA Center for Aviation Systems Reliability

Tech Area: Adhesively Bonded and Composite Structure (NAARP - NDI 3)

Task 1-1-A: Thermal Wave Imaging of Adhesive Bonds

Principal Investigators: R.L. Thomas, L.D. Favro, and P.K. Kuo

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Status last year:

Completed a design for a prototype cart and shroud for carrying the flashlamps and camera under hangar conditions.

Just completed (March 15-19, 1993) the first mini-field demo at the AANC hangar in Albuquerque.

Planning a second mini-field demo at Tinker AFB.

Current Status:

Completed the Tinker AFB mini-field demo (May 11-13, 1993)

Redesigned an improved cart and shroud system, based on the experience from the previous two mini-field demos.

Used the newly redesigned cart system in a third mini-field demo at the AANC hangar (March 14-18, 1994).

WSU T/T -1

Techniques for
Flaw Detection
RPI 199

FAA Center for Aviation Systems Reliability

Tech Area: Adhesively Bonded and Composite Structure (NAARP - NDI 3)

Task 1-1-A: Thermal Wave Imaging of Adhesive Bonds

Principal Investigators: R.L. Thomas, L.D. Favro, and P.K. Kuo

Technology Transfer Activity

Reported Status in preliminary information:
(Excerpted from Inspection Sub-Program Requirements Document (p. 5)

Stage 1: Laboratory Development 9/91
Stage 2: Laboratory Prototype 9/92
Stage 3: Field Prototype 3/94
Stage 4: Validation of Process 9/94
Stage 5: Tech Transfer
Stage 6: Commercialization

Updated Information:

Stage 5: A proposed CASR candidate for FY94 Tech Transfer

Stage 6: Electronics and software now available from Thermal Wave Imaging, Inc.; Two IR Camera companies currently negotiating agreements to market Integrated systems

WSU T/T -2

FAA Center for Aviation Systems Reliability

Tech Area:	Adhesively Bonded and Composite Structure (NAARP - NDI 3)
Task 1-1-A:	Thermal Wave Imaging of Adhesive Bonds
Principal Investigators:	R.L. Thomas, L.D. Favro, and P.K. Kuo

Technology Transfer Activity

Stage 4: Validation of Process

Inspection Results from May 13, 1994 Demonstration at Tinker AFB

[Excerpted from Letter of October 13, 1994 from Geoffrey O. Mitchell, Sr. Staff Engineer, ARINC]

Assessment of Fuselage Lap Joint Results (Area 1 and Area 5)

"The results summary contained in Table 1 suggests that the interpreted thermal image data provided detected nearly all the corrosion in Area 1 and over 50% of the corrosion in Area 5. It should be noted that Area 1 contained more severe corrosion than Area 5..........

The high false positive incidence suggests that there are other mechanisms at work in the lap joint which can cause no-conductivity areas and mislead interpretation. In addition, since these images were compared against percent material loss, it is possible areas of light corrosion may show up in the thermal image (because of corrosion product buildup) but not register as significant in the WL x-ray data.

In addition, I performed a visual assessment of the lap joint areas 1 and 5 using the thermal images provided. The left side of Area 1 had slightly more percent material loss than did Area 5. The thermal images of the left side of these areas show that Area 1 is primarily red and yellow in color and Area 5 is primarily green when compared to adjacent non-corroded (purple) structure. There appears to be good correlation in this region to the corrosion found in the lap joints."

WSU T/T -3

FAA Center for Aviation Systems Reliability

Tech Area:	Adhesively Bonded and Composite Structure (NAARP - NDI 3)
Task 1-1-A:	Thermal Wave Imaging of Adhesive Bonds
Principal Investigators:	R.L. Thomas, L.D. Favro, and P.K. Kuo

Technology Transfer Activity

Stage 4: Validation of Process

Inspection Results from May 13, 1994 Demonstration at Tinker AFB

[Excerpted from Letter of October 13, 1994 from Geoffrey O. Mitchell, Sr. Staff Engineer, ARINC]

Assessment of Fuselage Lap Joint Results (Area 1 and Area 5) [Cont'd.: 2nd layer corrosion]

"On Area 5 (refer to slide 28 enclosed), there is second layer corrosion (2-5% material loss) on sheets 4 & 5. This is located approximately between 18-24 inches (holes 6-8). The thermal image shows areas of red and yellow in this area. It may be possible that given the tightly spaced spot weld & fastener pattern, this corrosion damage amount produced an area of non-conductivity (due to corrosion product) in the second layer. If true, this would be a good indication of thermal imaging potential for detecting sublayer corrosion since there was no first layer (between sheet 1 and 4) corrosion in this area of the lap joint.

Overall there appears to be good detection in regions that showed significant corrosion damage. In addition, the thermal image data provided may show detection of second layer corrosion."

FAA Center for Aviation Systems Reliability

Tech Area:	Adhesively Bonded and Composite Structure (NAARP - NDI 3)
Task 1-1-A:	Thermal Wave Imaging of Adhesive Bonds
Principal Investigators:	R.L. Thomas, L.D. Favro, and P.K. Kuo

Technology Transfer Activity

Stage 4: Validation of Process

Use of a Thickness Calibration Strip

[Preliminary result from the March 11-15, 1994 AANC Mini-Field Demo]

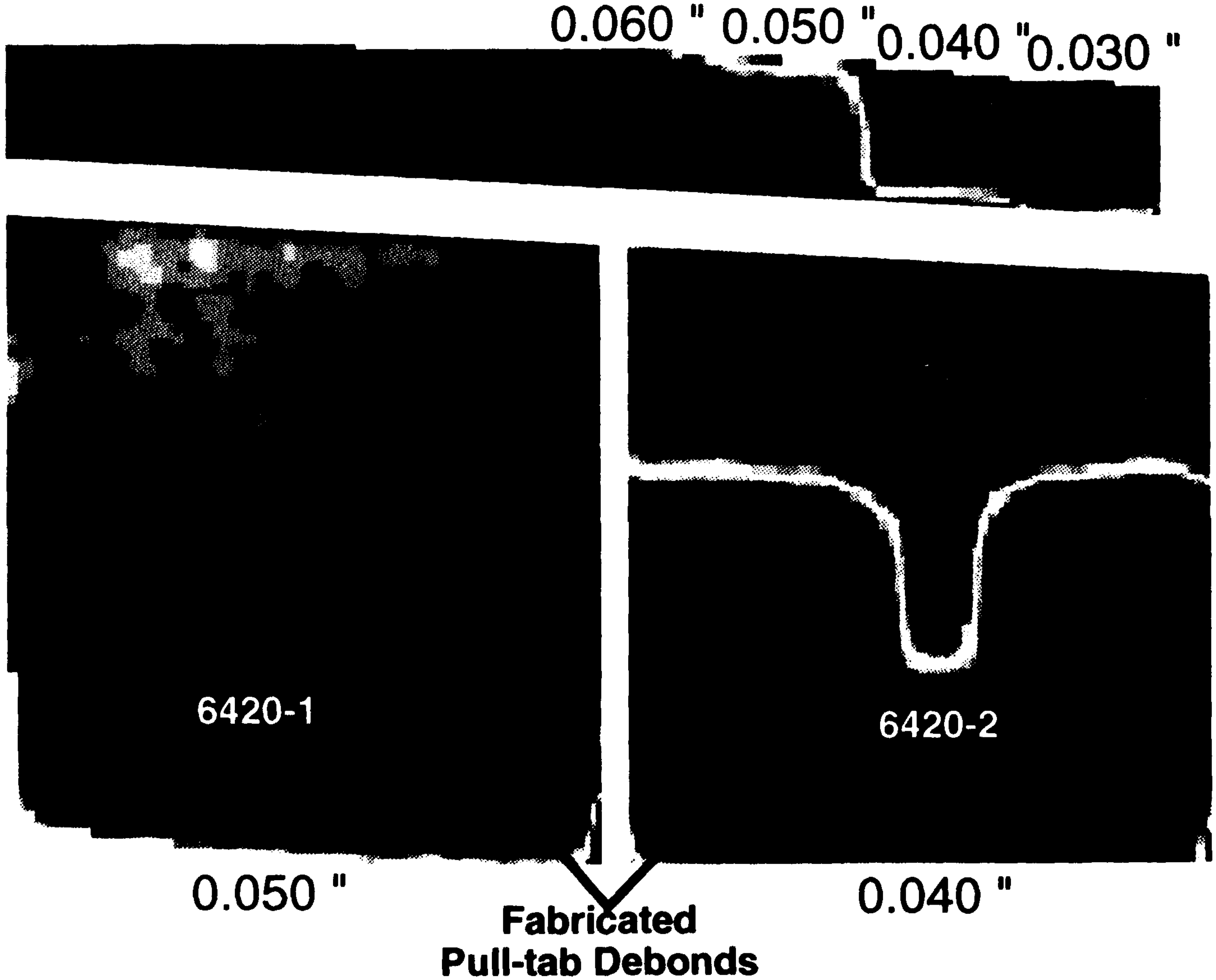
Thermal Wave Imaging of AANC Library Specimens #6420-1 and #6420-2 (Containing Pull-tab Disbonds)

The following Thermal Wave Images were made during our March 11-15, 1994 AANC Mini-Field Demo, in which we simultaneously imaged our Thickness Calibration Strip, and two AANC-Fabricated (from Boeing) Pull-Tab Disbond Test Specimens.

The disbonds in each of these test specimens are easily imaged, and their material thicknesses (0.050 inch for Specimen #6420-1 and 0.040 inch for Specimen #6420-2) agree very well with the indications on the thermal wave images of the Thickness Calibration Strip.

FAA Center for Aviation Systems Reliability (CASR)

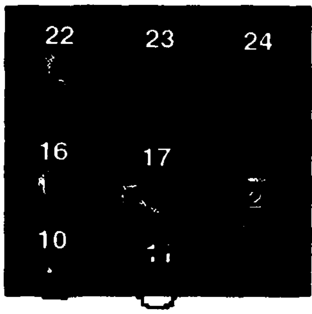
THICKNESS CALIBRATION STRIP



EXAMPLE OF TWO THERMAL WAVE IMAGES OF AN AANC-FABRICATED PULL-TAB DISBOND TEST SPECIMENS, SHOWN BELOW THE WSU THERMAL WAVE THICKNESS CALIBRATION STRIP. NOTE THE GOOD AGREEMENT BETWEEN THE THICKNESSES OF THE SPECIMENS AND THOSE INDICATED IN THE IMAGES.

WSU T/T -6

THERMAL WAVE IMAGING OF WING FASTENER CORROSION



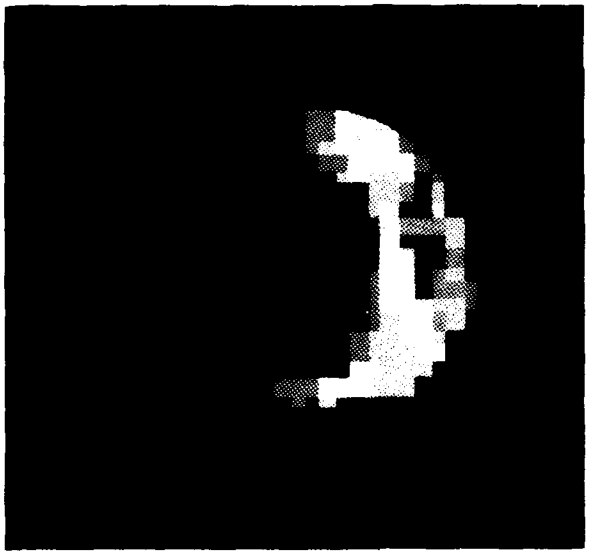
ENLARGEMENT OF REGION SURROUNDING FASTENER #17

Optical Micrograph of Section of Left Countersink region, Showing Exfoliation

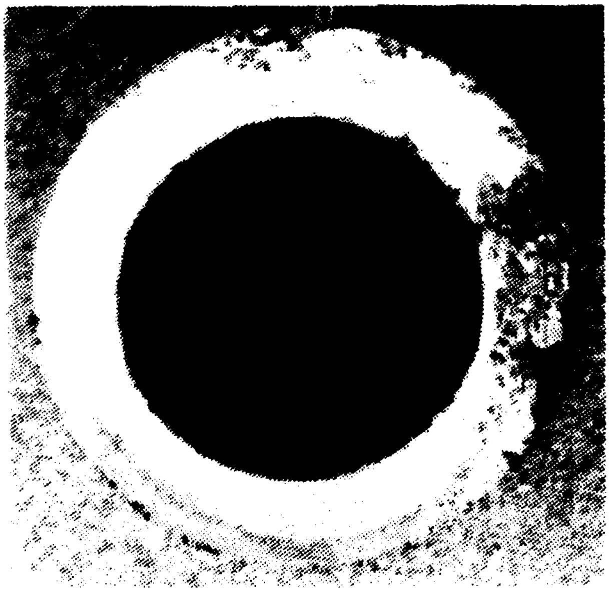
FAA Center for Aviation Systems Reliability (CASR)

THERMAL WAVE IMAGE OF FASTENER #76
(top down view)

2



OPTICAL IMAGE OF COUNTERSINK 76
(top down view)



WAYNE STATE UNIVERSITY
Institute for Manufacturing Research *IMR* WSU T/T -8

FAA Center for Aviation Systems Reliability

Tech Area:	Adhesively Bonded and Composite Structure (NAARP - NDI 3)
Task 1-1-A:	Thermal Wave Imaging of Adhesive Bonds
Principal Investigators:	R.L. Thomas, L.D. Favro, and P.K. Kuo

Technology Transfer Activity
Stage 4: Validation of Process

Inspection Results from May 13, 1994 Demonstration at Tinker AFB
[Excerpted from Letter of October 13, 1994 from Geoffrey O. Mitchell, Sr. Staff Engineer, ARINC]

Fastener Evaluations
"The fastener corrosion results clearly show regions of significant pitting (> .002" deep) that correspond closely with the "half moons" on fasteners 1,2, 10,16,17,22,26,27,28,29, and 39. The correlation is not perfect on all fasteners, but is especially good on fasteners 1,2,22,26,27,29, and 30. Fasteners with significant corrosion but no indication were observed on the thermal image are 4,5, 11, and 31.

The metallographic and IU [immersion ultrasonic] results clearly indicate a severe (multiple layers region of exfoliation to the left of fastener 17. The thermal image clearly indicates an area of relative non-conductance to the left of this fastener which suggests good correlation."

FAA Center for Aviation Systems Reliability

Tech Area:	Adhesively Bonded and Composite Structure (NAARP - NDI 3)
Task 1-1-A:	Thermal Wave Imaging of Adhesive Bonds
Principal Investigators:	R.L. Thomas, L.D. Favro, and P.K. Kuo

Technology Transfer Activity

Stage 4: Validation of Process [Cont'd]

Inspection Results from May 13, 1994 Demonstration at Tinker AFB
[Excerpted from Letter of October 13, 1994 from Geoffrey O. Mitchell, Sr. Staff Engineer, ARINC]

Fastener Evaluations : Observations and Conclusions

"Some possible rationale for the indications observed may be the normal variations in tolerance associated with seating a conical object (fastener head) into a conical surface (countersink). It is likely that not all fasteners will have 100% contact and variations caused during countersinking operations could lead to non-contact in some areas. Any gap of this type is probably small (approx. .001-.003), but may be sufficient to cause an area of non-conductivity and act as an excellent crevice for moisture entrapment. This rationale also provides explanation for indications on the newly installed and reworked fasteners. If true, this particular outcome offers application potential for hole/fit quality inspections of installed fasteners. Solutions for corrosion detection inside the fastener head may be possible if a definitive correlation could be established."

FAA Center for Aviation Systems Reliability

Tech Area: Adhesively Bonded and Composite Structure (NAARP - NDI 3)

Task 1-1-A: Thermal Wave Imaging of Adhesive Bonds

Principal Investigators: R.L. Thomas, L.D. Favro, and P.K. Kuo

Technology Transfer Activity

Stage 6: Commercialization

Preliminary Activities

Thermal Wave Imaging, Inc., Lathrup Village, MI

- Dr. Steven Shepard, President, has assisted WSU in the mini-demos.
- The WSU intellectual property in thermal wave imaging has been licensed to TWI.
- TWI has developed a commercially available version of the WSU hardware & software, implemented on a PC-486 platform (EchoTherm IV™).
- TWI fabricated the shroud and constructed the cart used in the March, 1994 mini-field demo at AANC, according to WSU specifications, and at TWI expense.

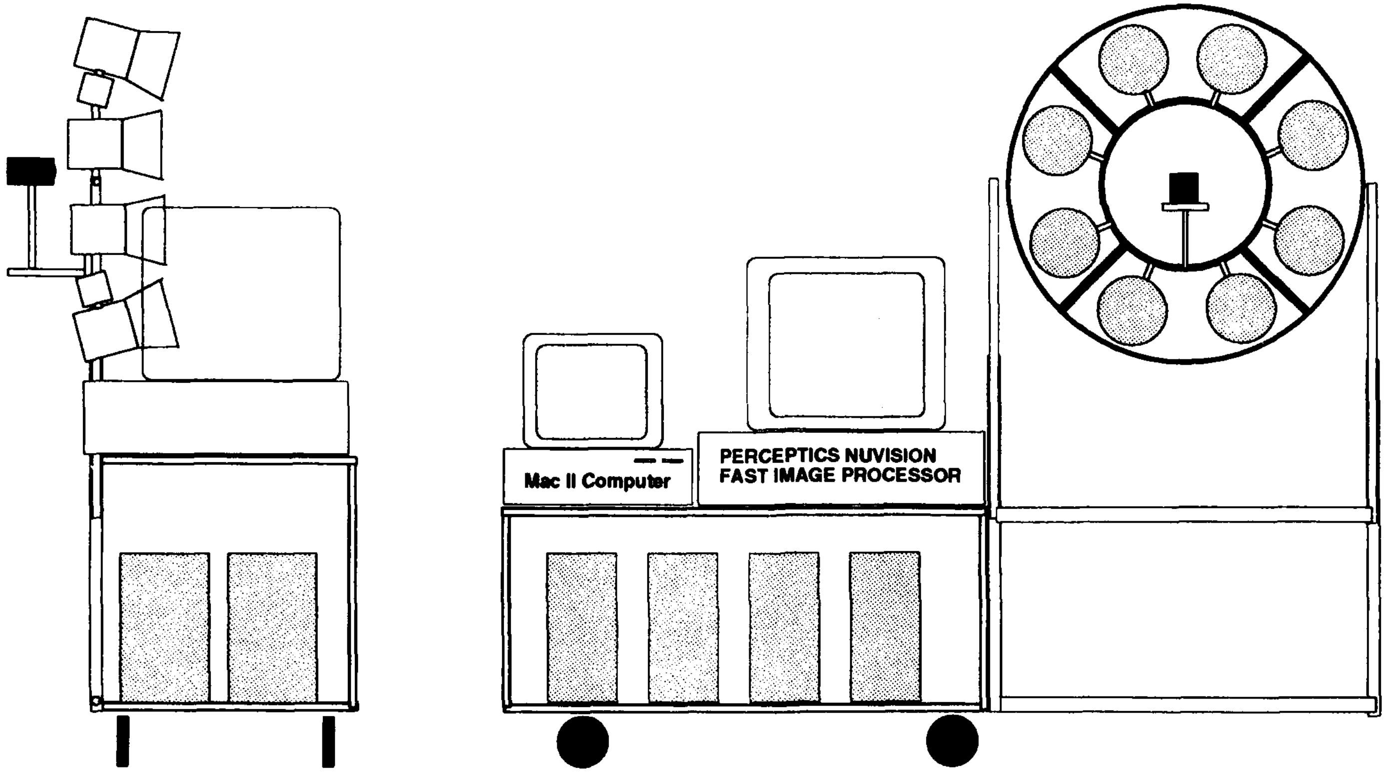
Inframetrics, Inc., Billerica, MA

- Inframetrics has loaned the IR 740 infrared camera used in the mini-demos.
- Inframetrics is a strong, near-term, potential partner for TWI to market the EchoTherm IV™ electronics and software.

Requirements for an "Off-the-shelf "System for Aviation Systems Inspection Applications

- A commercial system for use in an aircraft maintenance hanger must:
  Be relatively light, and have a small "footprint" for access to scaffolding.
  Be highly maneuverable, to enable fast positioning in a variety of geometries
  Needs uniform flashlamp illumination to avoid possible artifacts from uneven heating.

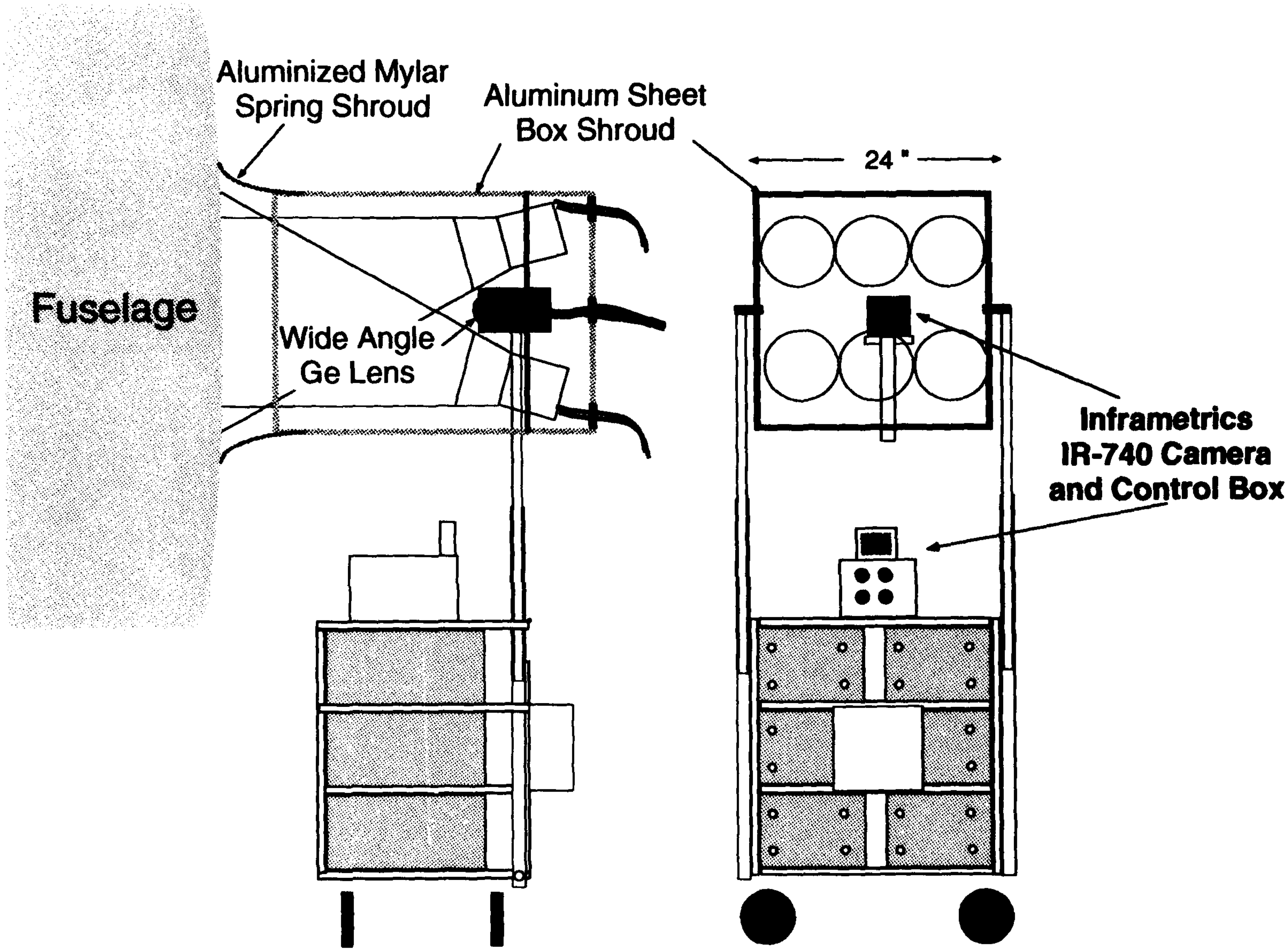
CART USED FOR June,1992 MINI-FIELD DEMO, Northwest Airlines



Deficiencies:
- Too heavy (power supplies on the cart)
- Too many flash lamps (8), and therefore unecessarily expensive
- Inadequate Shroud (aluminized mylar)
- Not sufficiently maneuverable
- Stand-alone Perceptics image processor (too expensive & heavy) with Mac II computer (too expensive & heavy; non-standard for industry)
  [Replaced in 1992 by TWI EchoTherm IV™]
- Cumbersome and heavy cart

WSU T/T -12

CART USED FOR MARCH 1993 AANC MINI-FIELD DEMO



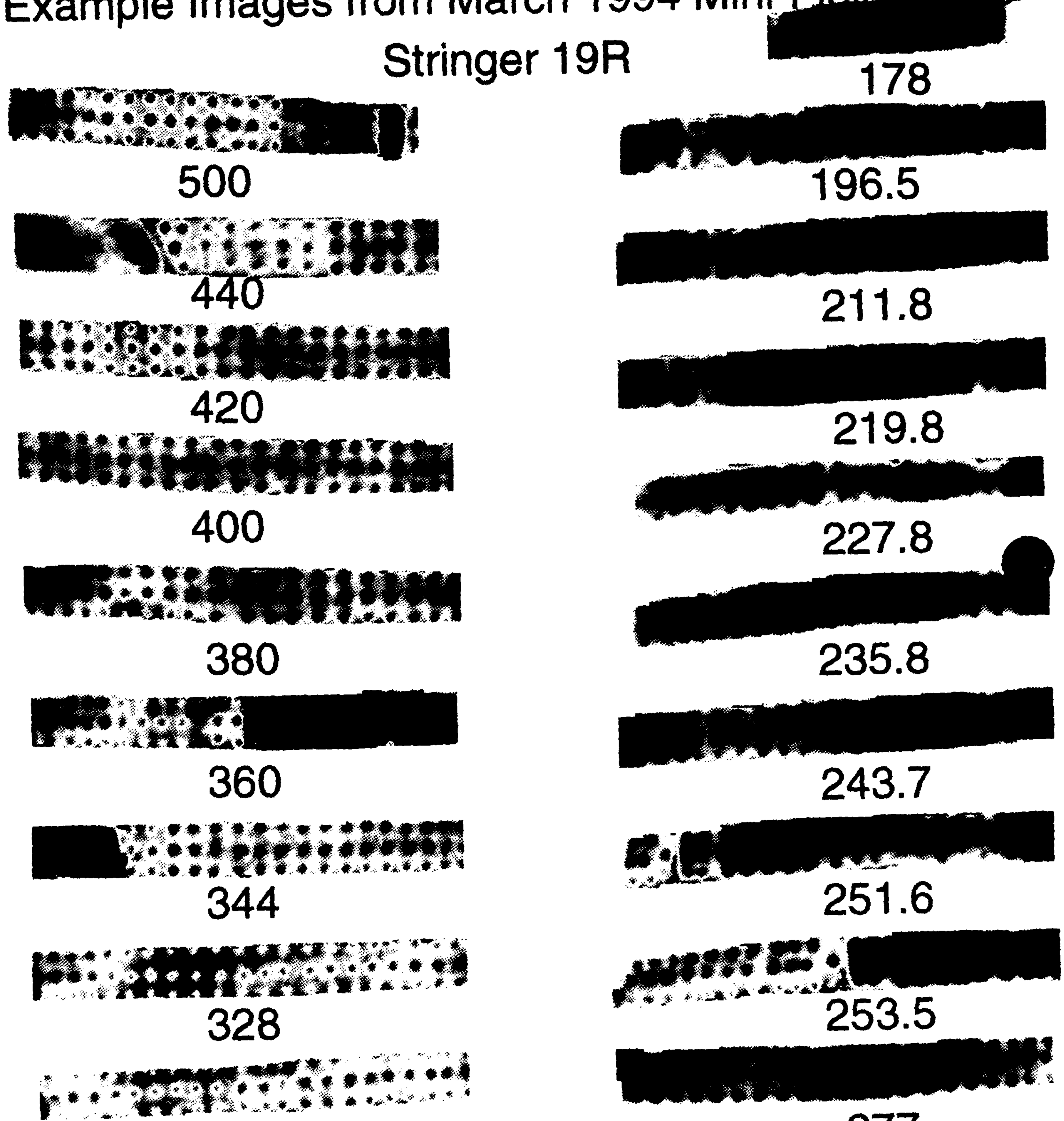
Deficiencies:

- Too heavy (power supplies on the cart)
- Too many flash lamps (6), and therefore unecessarily expensive
- Not sufficiently maneuverable

WSU T/T -13

Example Images from March 1994 Mini-Field Dem

Stringer 19R



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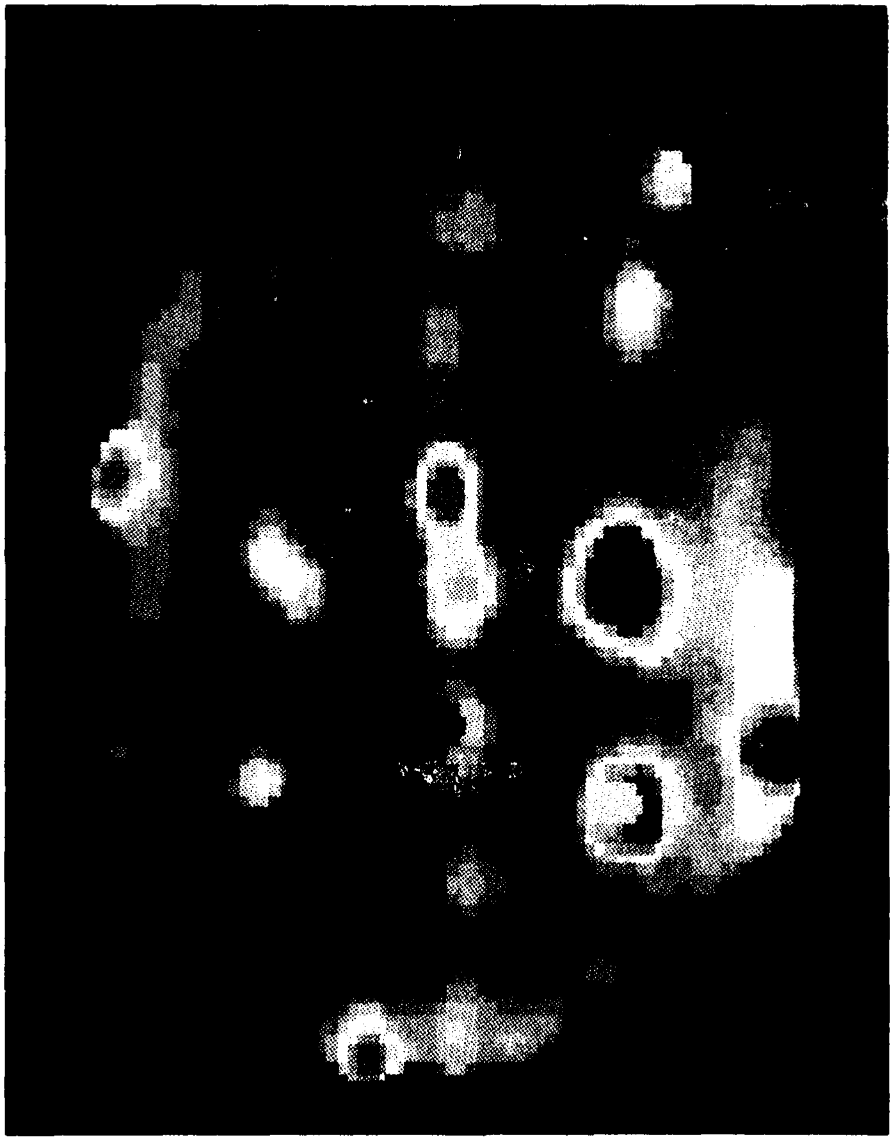
WSU T/T

Example Image from March 1994 Mini-Field Demo

Boron repair patch - 737 aircraft



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Institute for Manufacturing Research IMR

WSU T/T -16

Techniques for Flaw Detection
RPI 199

FAA Center for Aviation Systems Reliability

Tech Area:	Adhesively Bonded and Composite Structure (NAARP - NDI 3)
Task 1-1-A:	Thermal Wave Imaging of Adhesive Bonds
Principal Investigators:	R.L. Thomas, L.D. Favro, and P.K. Kuo

Progress Report

Objectives

The objective of this research project initiative (RPI 199) is "to develop improved inspection technologies to address specific aging airframe inspection problems. cost effective inspection methods employing advanced traditional technologies, emerging technologies, or combinations of technologies will be investigated for their ability to accurately and reliably detect cracks, disbonds, and corrosion damage."

Thermal Wave Imaging is an emerging technology which is being investigated for its potential application to detect disbonds and corrosion damage.

Approach

Pulse-echo thermal wave methodology is applied, including theory, experimental testing on fabricated laboratory specimens, assembly of prototype field instrumentation, and mini-field demonstrations in hangar environments.

Progress

Theory and numerical modeling are in good agreement with experiments on fabricated test specimens, indicating the important temperature-time profiling parameters.

Several generations of carts, flashlamps and shrouds have been assembled, and a technology transfer prototype version is the next logical step.

The March, 1994 mini-field demo at AANC tested the logistics of the cart, shroud and flashlamp systems, demonstrating inspection speeds of 90 feet/hour.

WSU Prog. -1

FAA Center for Aviation Systems Reliability

Tech Area:	Adhesively Bonded and Composite Structure (NAARP - NDI 3)
Task 1-1-A:	Thermal Wave Imaging of Adhesive Bonds
Principal Investigators:	R.L. Thomas, L.D. Favro, and P.K. Kuo

Mini-Field Demo, March, 1994

Objectives

•To minimize the number of flashlamps and power supplies (and hence cost) of the revised system.
[Result: Reduced from six lamps to four - some unevenness of heating, which we plan to correct by a redesign of the the flashlamps and shroud during the proposed Technology Transfer Project during the next 12 months.]

•To make the overall prototype system lighter and more maneuverable around the aircraft.
[Result: The reduction in number of lamps, addition of longer cables so that the power supplies can stay on the hangar floor, and the addition of a motorized actuator and hand winch all proved to be substantial improvements, and a rate of 90 feet /hour was achieved, including all operations such as image storage, etc. The cart should next be made lighter, smaller, and should have additional degrees of alignment freedom, as part of the Technology Transfer Plan.]

•To standardize the pulse-echo instrumentation settings for better comparison of images taken from different regions of the aircraft.
[Result: The pulse gate widths and time settings were decreased from those used in the 1993 mini-field demo, and were kept constant, with a uniform color map, for all of the imaging. The result was to emphasize the short-time behavior, and thus, the first layer corrosion and disbond inspection.]

•To further investigate the feasibility of using thickness calibration strips for more quantitative measurements.
[Result: This technique was tested successfully on the adhesion disbond test specimens (see WSU Slide T/T-6).]

WSU Prog. -2

Dual-Band Infrared (DBIR) Imaging for Inspection of Aging Aircraft

Presented to
Aging Aircraft Inspection Program Review

at
Center for Aviation Systems Reliability
Ames Iowa

by
Nancy Del Grande
and
Kenneth Dolan

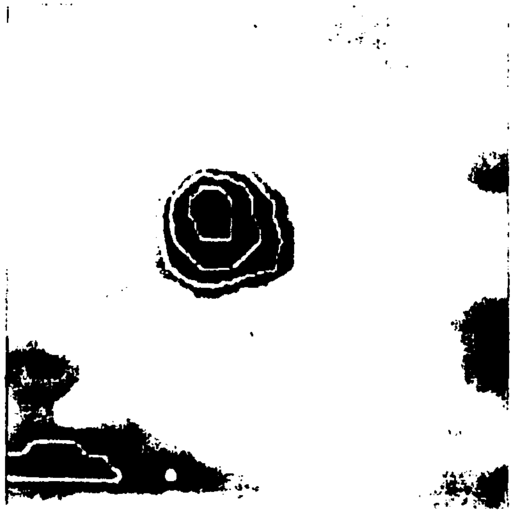
April 5-6, 1994

Lawrence Livermore National Laboratory

Dual-band infrared (DBIR) imaging provides background-corrected thermal maps

DOE: Aquifers in 6 m of soil

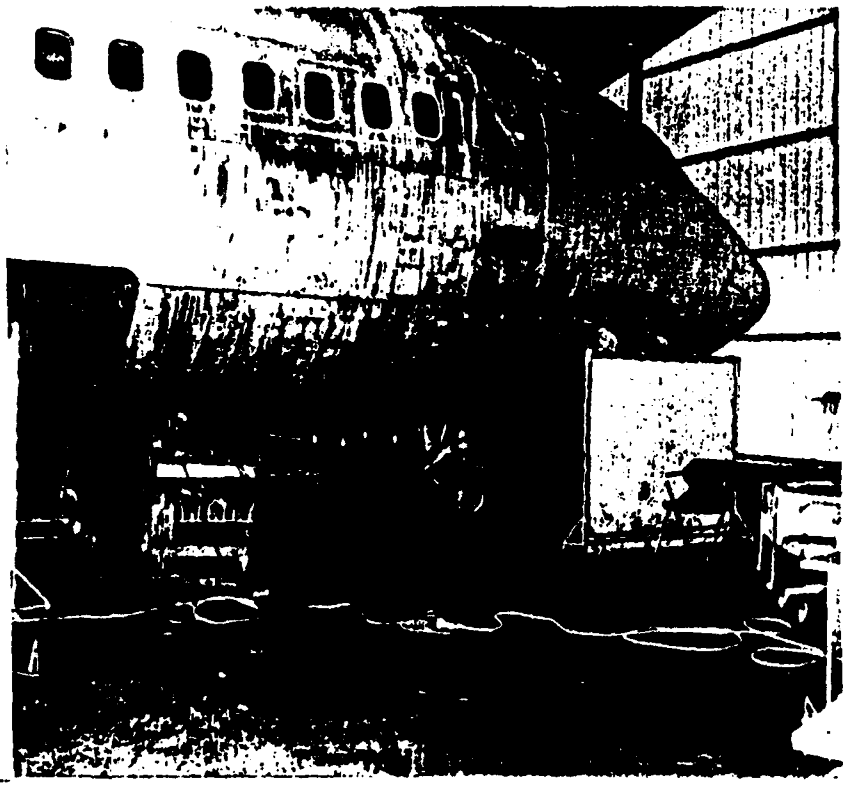
DOD: Mines buried under 15 cm of sand



FAA: Hidden flaws (disbonds) in aircraft panels

The patented dual-band infrared (DBIR) thermal mapping method uncovers aquifers, landmines and aircraft defects

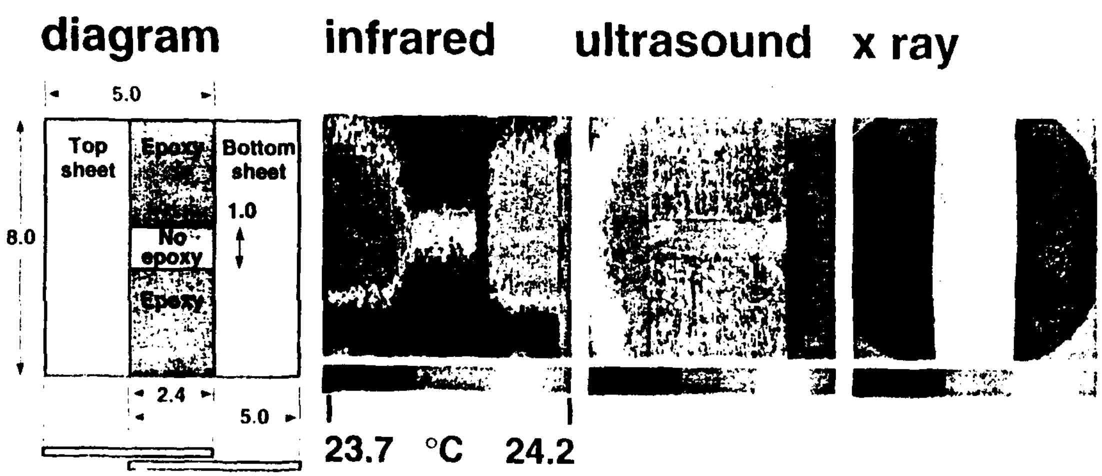
Our program is focused on adapting DBIR thermal imaging to flaw detection in fuselage and wing skins



Progam Elements:

- DBIR methods development
  - Laboratory tests
  - Computer modeling
  - Defect detection & tagging
  - Hangar demonstrations
- Prototype DBIR system
  - System specifications
  - Commercial procurement
  - DBIR customization
  - Hangar demonstrations
- Subcontract - GE Aircraft Engines
  - IR crack detection
  - Rotating component samples
  - Laser & other heating methods

Our laboratory tests use multiple methods to characterize lap joint disbonds



DBIR thermal imaging is fast, noncontact and safe

Dual-band infrared (DBIR) imaging is uniquely qualified for large area inspection

- DBIR is a *global inspection method* for detection of hidden defects (e.g. disbonds, corrosion thinning, delaminations)
- Requires minimal surface preparation - no paint stripping
- Provides quantitative measure of corrosion thinning
- Provides flaw/damage assessment for composites
- Provides high quality data-base images for baselining and in-service inspection histories

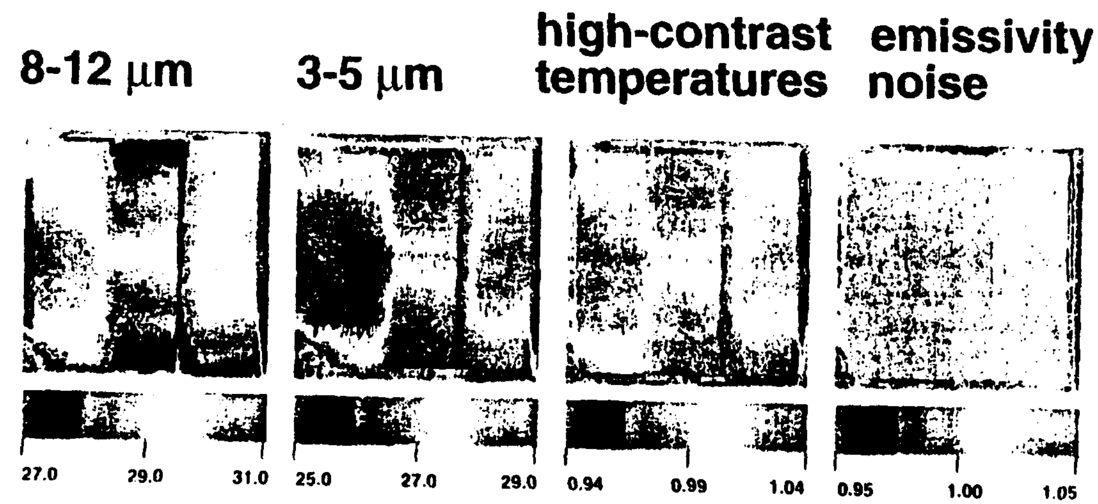
DBIR large area scanning has potential for reducing aircraft out-of-service time, surface preparation and manpower costs

DBIR thermal imaging clarifies interpretation of airframe defect maps

- Defect map signal-to-clutter ratios were typically ten times higher for two band IR, than one-band IR thermal imaging
- Corrected thermal maps were free of false defect sites after emissivity maps were used to tag and remove surface clutter
- To quantify corrosion damage, we correlated 12% thickness loss with 0.5 °C temperature rise at 0.4 s after the heat flash
- Shallow and deeper airframe defect sites were depicted on early-time and late-time thermal inertia maps

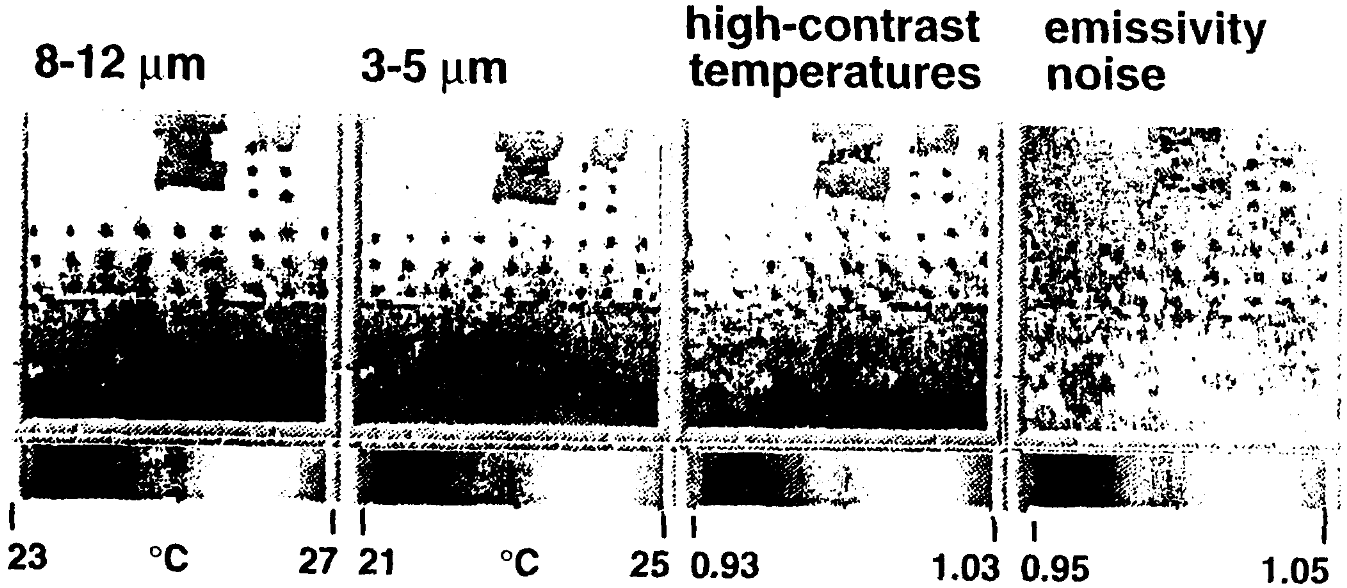
DBIR provides high-quality data of disbond site, area and percent thickness loss from corrosion damage

We combined two infrared bands to produce high-contrast temperature and emissivity-noise maps



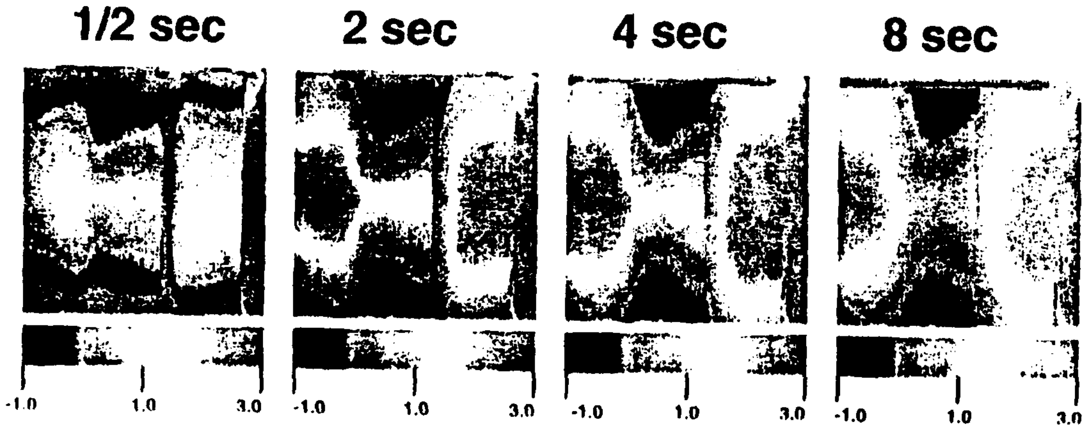
Emissivity noise variations from clutter were negligible when black paint was applied evenly to lap joint surface

AANC hanger tests of Boeing 737 lap joint area use DBIR images to remove clutter



Emissivity-noise maps tag clutter from tape markers (top), rivet sites (within lap splice) and uneven paint (at bottom)

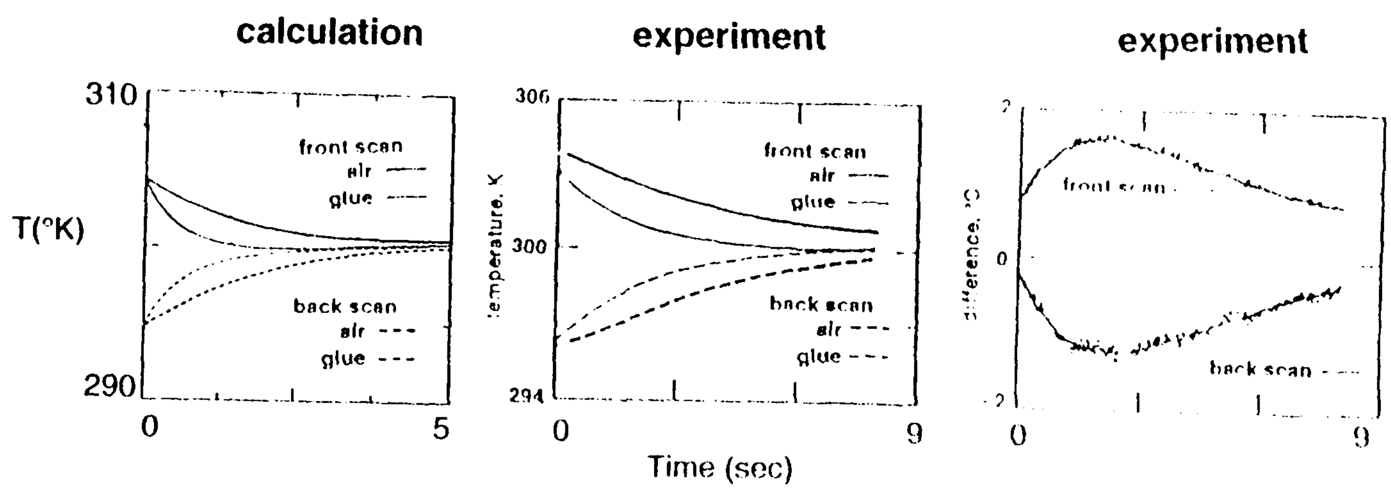
Laboratory tests show maximum contrast (1.6 °C) for lap joint disbond 2 seconds after flash



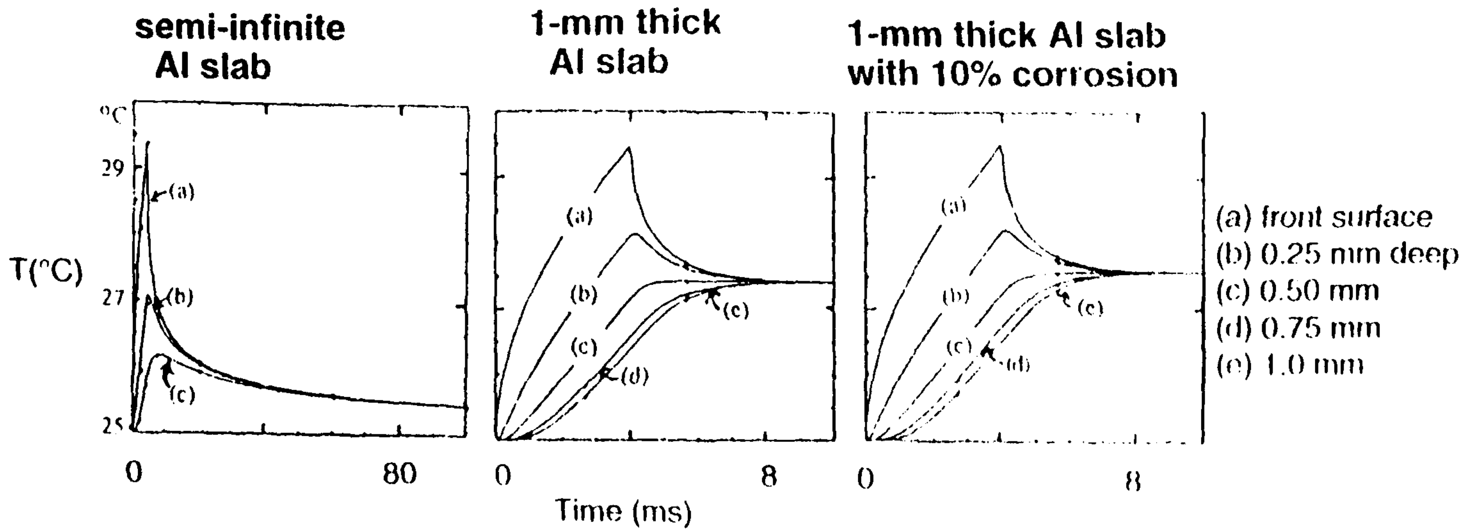
We study late-time thermal images for air gap disbonds and early-time thermal images for corrosion thinning

Calculations with Topaz-2D/3D are used to guide test methods development

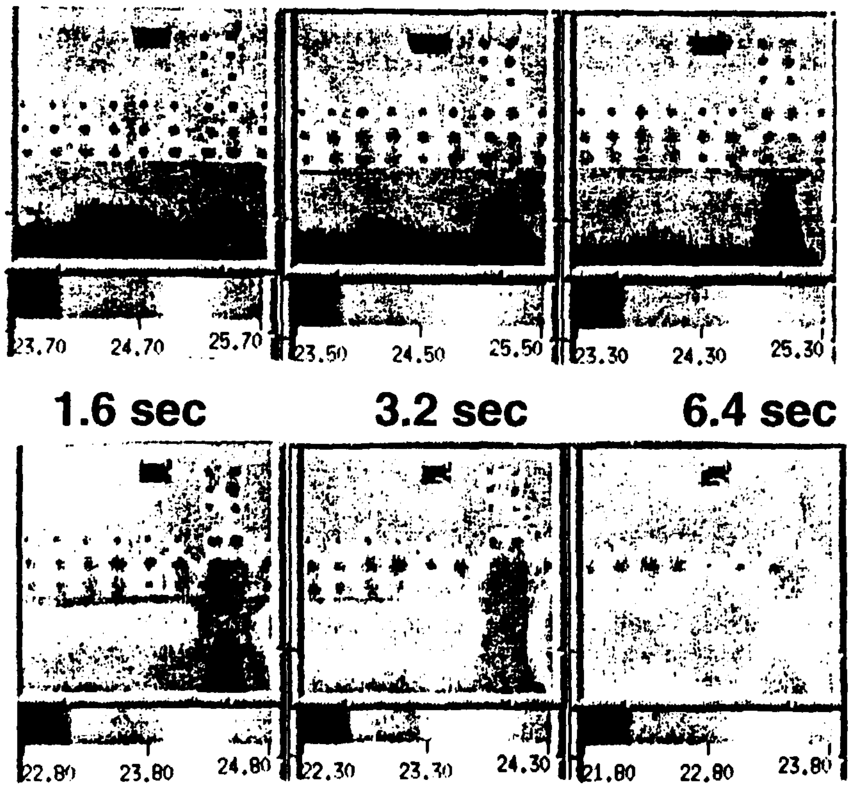
Lap joint disbond sample



Corrosion thinning calculations



Boeing 737 lap joint corrosion damage defects are best measured 0.4 seconds after flash



We choose one time-frame per IR band to optimize corrosion damage analysis

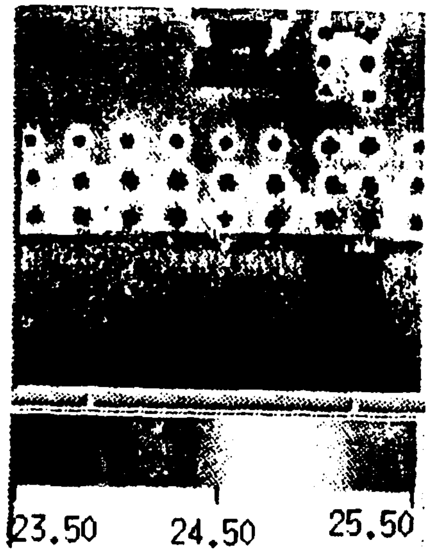
Thermal Inertia maps are used to determine approximate flaw depths in layered airframes

- Thermal inertia $(K\rho C)^{1/2}$ is a measure of resistance to temperature change
- Thermal inertia is sensitive to bulk thermal properties
- Thermal inertia maps show amount of damage from corrosion
- Early- and late-time thermal inertia maps provide approximate depth and layer where damage occurs

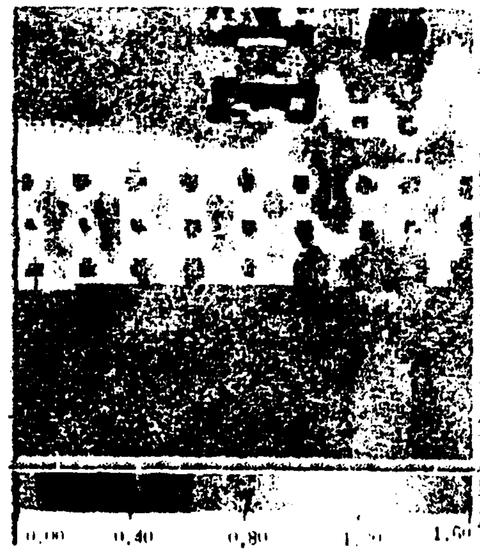
Thermal inertia maps show defects within deep underlying structures

Boeing 737 lap joint sites with 12% corrosion loss are red on temperature map and green on thermal inertia map

temperature map
(0.4 sec)



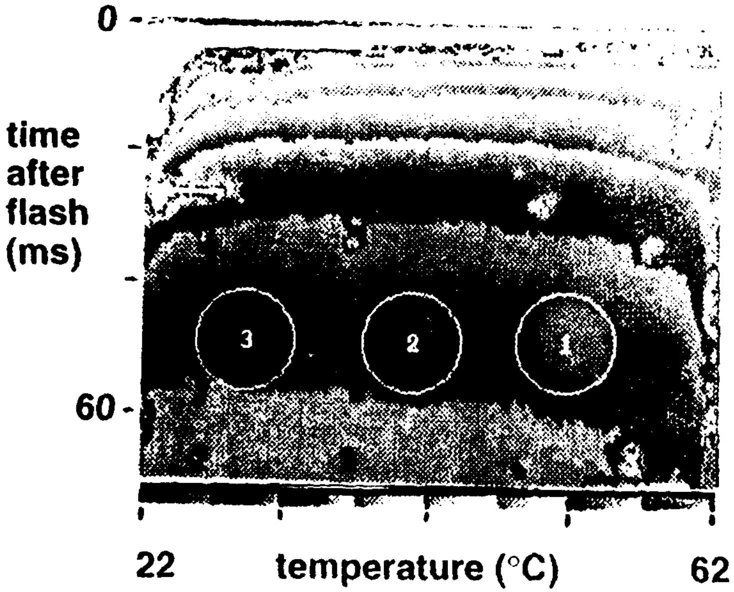
thermal inertia map
(1.6 to 8.0 sec)



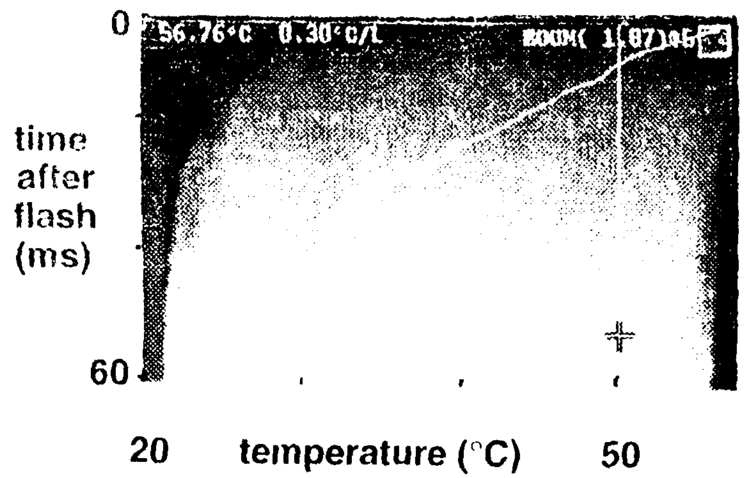
Late-time thermal inertia map shows corrosion entering lap joint area from inside aircraft

Thermal image scans and timegrams of panels with flat bottom holes were used to quantify material loss

Thermal image scan of flat bottom hole sites in 0.043 inch thick panel

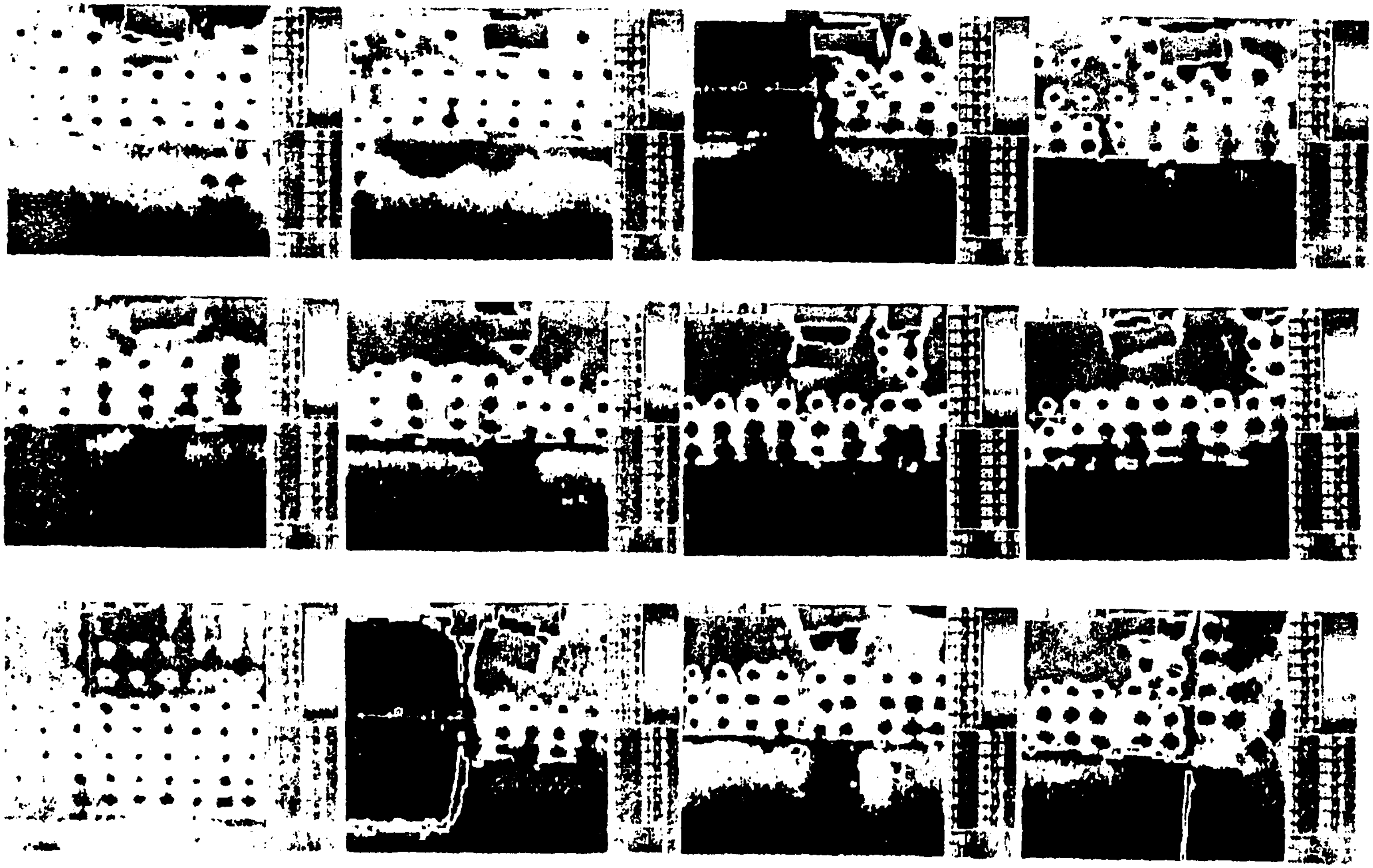


Fast (550 μs) thermal line scan of Site 1 timegram



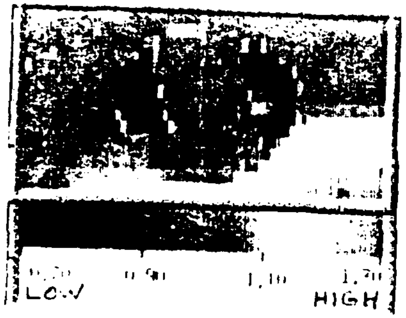
Thermal inertia from early temperature-time histories at 5-7 ms after flash will be used to distinguish ripples from material loss

Boeing 737 lap joint corrosion damage is 2-4% (green), 5-9% (yellow) or >10% (red)

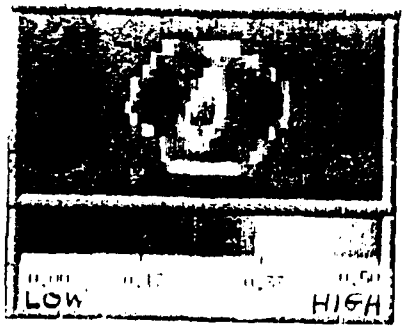


Composite sample thermal and thermal inertia maps show shallow to deep layer defects

Graphite-epoxy dome thermal inertia maps



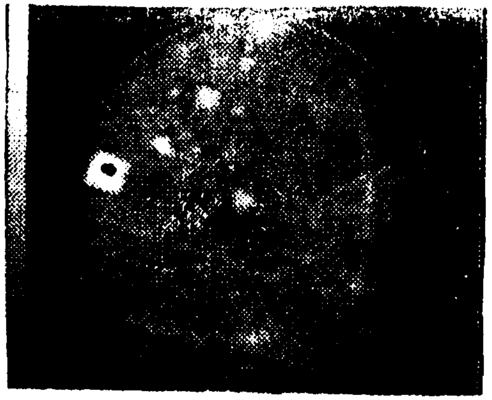
0.2 - 1.0 sec



2.8 - 8.0 sec

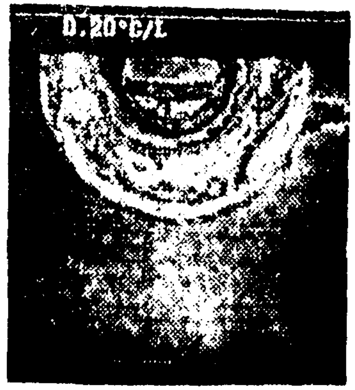
Graphite-epoxy dome temperature maps

0.55 sec

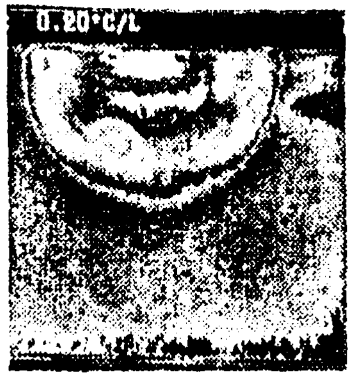


1.1 sec

Thermoplastic wing patch temperature maps



1.5 sec



25 sec

Summary

- Dual-Band Infrared imaging is fast, noncontact, one-sided and safe
- Our emissivity-corrected thermal maps remove surface clutter
- Our corrosion-defect maps quantify 6% or more thickness loss relative to surroundings and identify corrosion intrusion layer
- Our early-time thermal inertia maps distinguish disbonds and corrosion defects from ripples and bulges
- We detect composite defects which occur in shallow and deep layers

GE Aircraft Engines

GEAE is developing fast IR scanning methods to automate crack detection in rotating components

Objectives

Detect cracks in engine components with infrared imaging

Challenges

Disparity between materials and surface finishes

Results to date

Have determined that etched cracks are easily detected

Next Step

New test specimens
Optimize test parameters

IR image of 0.030 inch crack in Ti 6-4, etched surface

Management Plan - Objectives

Dual-band Infrared Imaging Project:

1. Determine if Dual-Band Infrared (DBIR) imaging can be adapted to inspection of aircraft components and structures

2. Develop an FAA customized DBIR prototype through system specifications and procurement

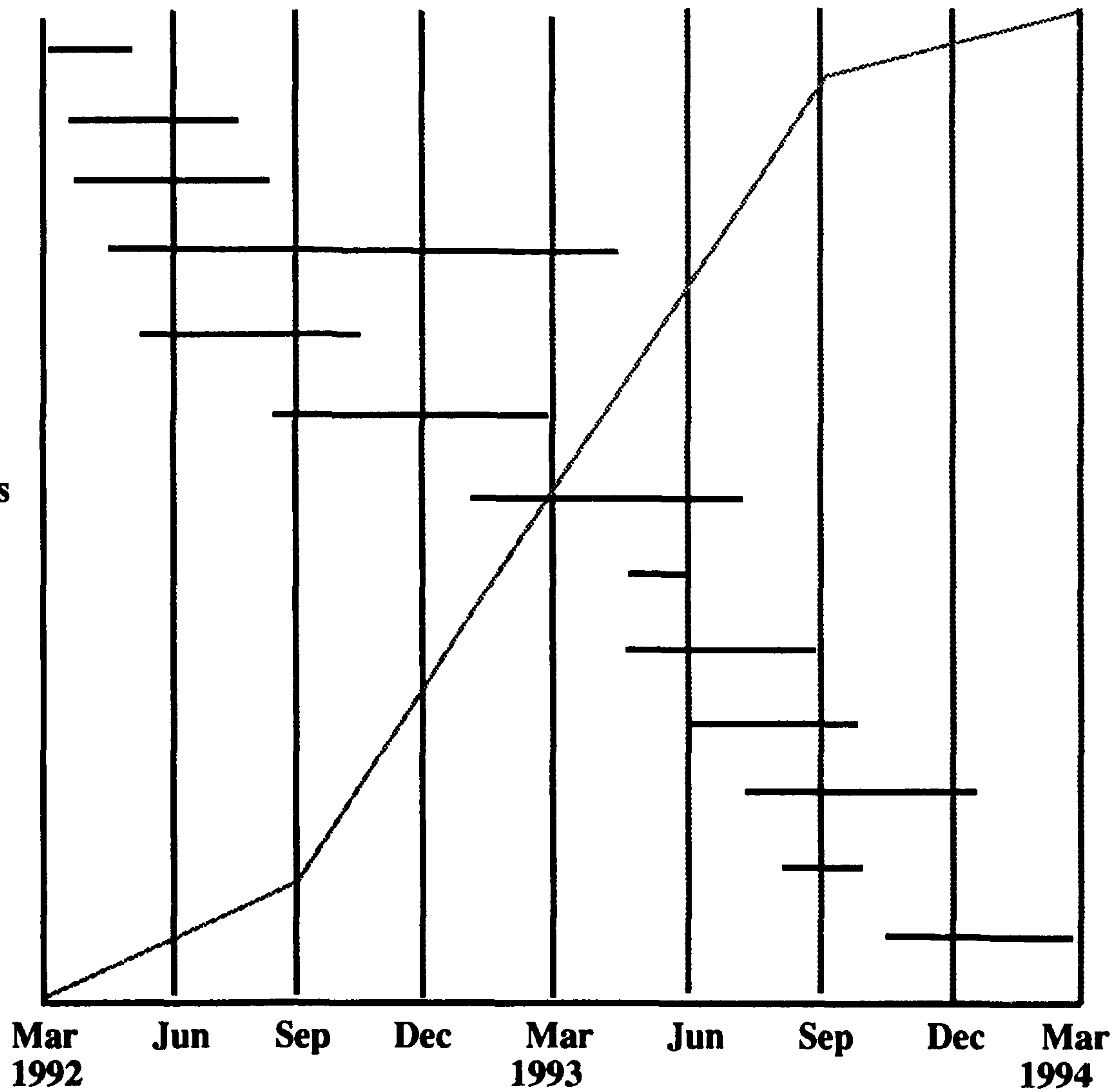
3. Develop subcontract with GE Aircraft Engines for crack detection by infrared imaging

4. Develop DBIR image interpretation methods for defect characterization

Program Management

Task 1: Adapt DBIR to aircraft inspection

- Define Problems & needs
- Develop heating methods
- Develop test samples
- Apply computational models
- Apply DBIR to painted and unpainted metal surfaces
- Apply DBIR to lap joint disbonds
- Apply DBIR to corrosion samples
- Demonstrate DBIR at AANC
- Develop thermal inertia methods
- Quantify corrosion loss
- Apply DBIR to composites
- Prepare summary report
- Develop fast imaging methods



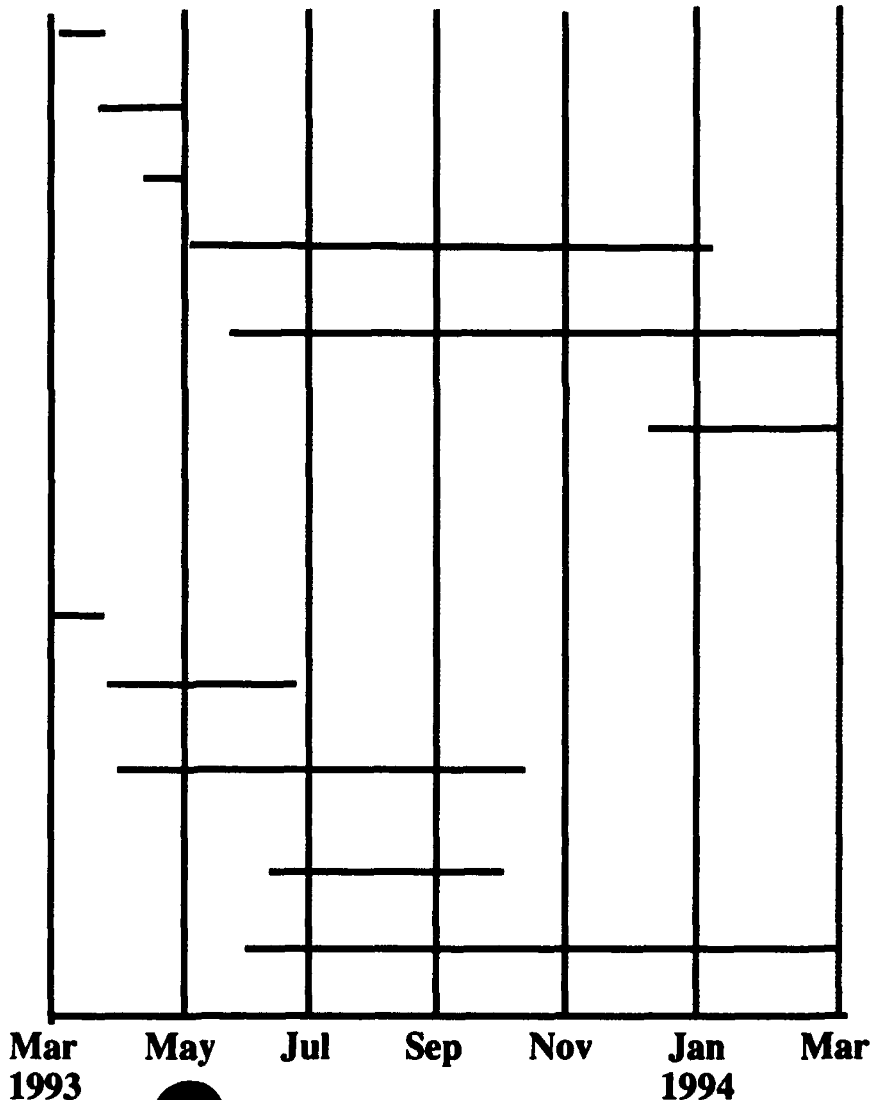
Program Management

Task 2: DBIR Prototype System

- Develop specifications
- Procure prototype system
- Demonstrate at AANC
- Enhance dual band capabilities
- Apply DBIR to lap joints, corrosion samples and composites
- Enhance fast timing capabilites

Task 3: GEAE Subcontract

- Finalize contract
- Procure Al test samples
- Obtain USAF release of nickel & titanium samples
- Develop statistical methods
- Apply laser heating and IR imaging methods



Technology Transfer Plan

- LLNL Technology Transfer Office has developed a patent position for licensing DBIR imaging method to private industry
- We have established a vendor capability through procurement of a thermal imaging system that meets prototype DBIR system specifications
  - We are working with the vendor to modify the FAA prototype DBIR system with 550 μs line scans which allows measurements at 1 - 10 ms after flash
  - Defect classification software and thermal inertia mapping will be adapted to the prototype DBIR system and stand-alone workstations
- Broad Agency Announcements will be made to offer technology transfer opportunity
- DBIR tech transfer will be offered by LLNLTechnology Transfer Office through publications, industry shows and announcements

Techniques for Flaw Detection
RPI 199

FAA Center for Aviation Systems Reliability

Project:	Adhesively Bonded and Composite Structure (NAARP-NDI 3)
Task 2:	Ultrasonic Characterization of Adhesive Bonds
Principal Investigator:	D. K. Hsu
FAA Sponsor:	R. Yarges
FAA Technical Monitor:	D. Galella
Industrial Contacts:	Delta Airlines, Northwest Airlines, United Airlines, Boeing, McDonnell Douglas, AANC

Techniques for Flaw Detection
RPI 199

FAA Center for Aviation Systems Reliability

Task 2: Ultrasonic Characterization of Adhesive Bonds

Objective: To develop ultrasonic techniques for detecting and sizing disbonds and corrosion in adhesively bonded aluminum skin structures.

Deliverables:

- 12/92 Technical Note on procedures for producing simulated corrosion samples using electrochemical process.
- 6/93 Interim Report on low frequency scan method.
- 9/93 Laboratory test coupons of aluminum lap splices containing characterized corrosion.
- 9/94 Final Report on test procedures and scan parameters for low frequency UT as applied to lap splices. Provide design and specifications for initial bubbler.

Techniques for Flaw Detection
RPI 199

FAA Center for Aviation Systems Reliability

Task 2: Ultrasonic Characterization of Adhesive Bonds

Accomplishments to date:

- Developed low frequency ultrasonic scan method for detecting disbond and corrosion in adhesive bonds. Compared test results with model calculation and with other NDI methods.
- Developed "Dripless Bubbler" that allowed closed-cycle, water-coupled C-scans with focused beam of low or high frequency ultrasound.
- Tested dripless bubbler with commercial handscanners on realistic skin panels.
- Demonstrated dripless bubbler on McDonnell Douglas MAUS III and acquired images.
- Designed and built a portable mortorized scanning bridge for dripless bubbler for inspecting fuselage lap splices containing buttonhead rivets.

Tested same on Boeing 747 at Northwest Airlines.

Task 2: Ultrasonic Characterization of Adhesive Bonds

Outline of Presentation:

- Current practice of ultrasonic NDI for lap splices and existing problems.
- "Doing focused immersion UT without the water mess" -- toward better signal-to-noise and finer spatial resolution in ultrasonic imaging of adhesively bonded structures using the dripless bubbler.
- The dripless bubbler scanning bridge built at CASR and preliminary results.
  Scan results obtained in field trial on NWA Boeing 747.
- Images acquired by combining the dripless bubbler and the MAUS III.
- The low frequency scan method and its advantages in detecting disbonds below scrim cloth and second layer corrosion.
- Results obtained on fatigue induced disbonds and on Boeing corrosion sample.

Difficulties of Contact Mode Ultrasonic NDI

- Cannot separate defect response from substructures without the aid of an image.
- Excessive variability in coupling conditions, e.g., pressure, tilt of transducer.
- Obstruction by surface protrusions such as buttonhead rivets.
- Resolution limited by transducer size.

(Last three also apply to motorized contact scans)

Advantages of Dripless Bubbler

- Closed-cycle water coupling -- compatible with hangar environ ment.
- Highly reproducible coupling condition leads to immersion quality scans.
- Using focused beam for improved spatial resolution.
- Scans freely over buttonhead rivets.

(Extra items needed: bubbler housing, mounting fixtures to scanner, water pump, wet vacuum)

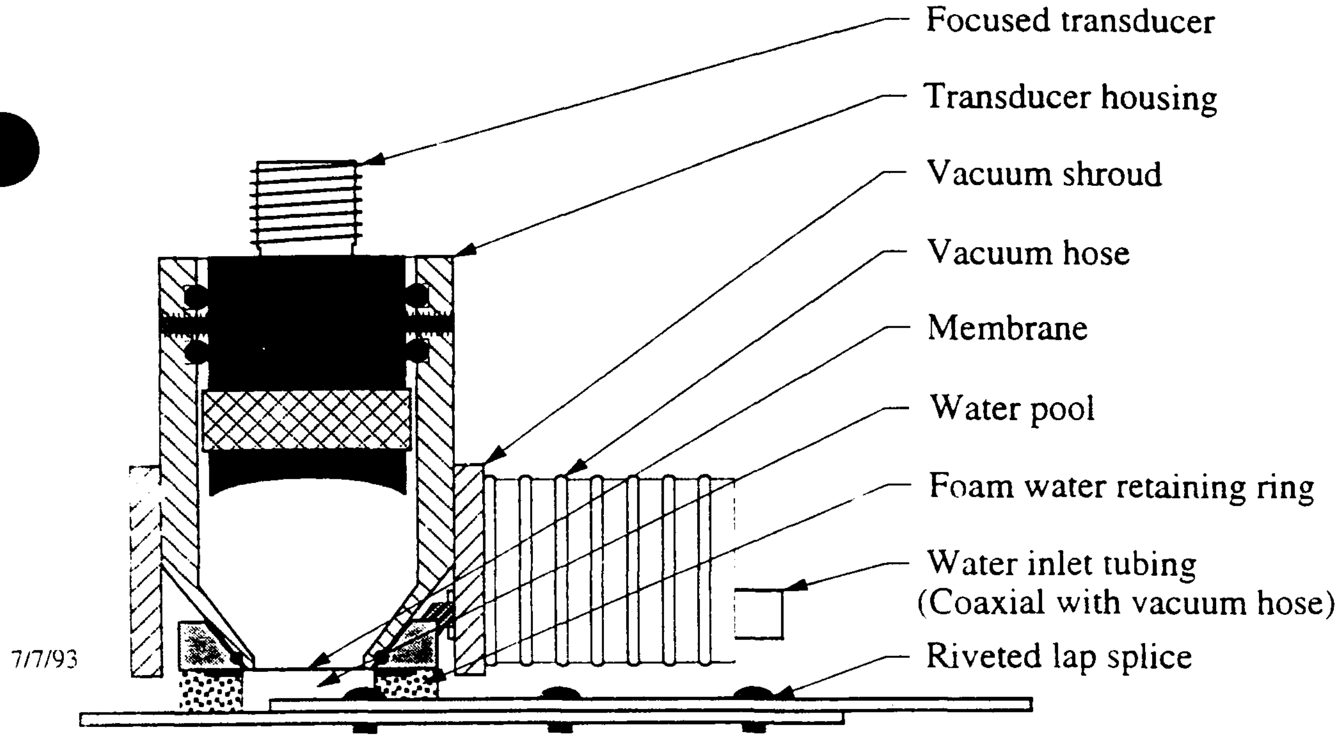
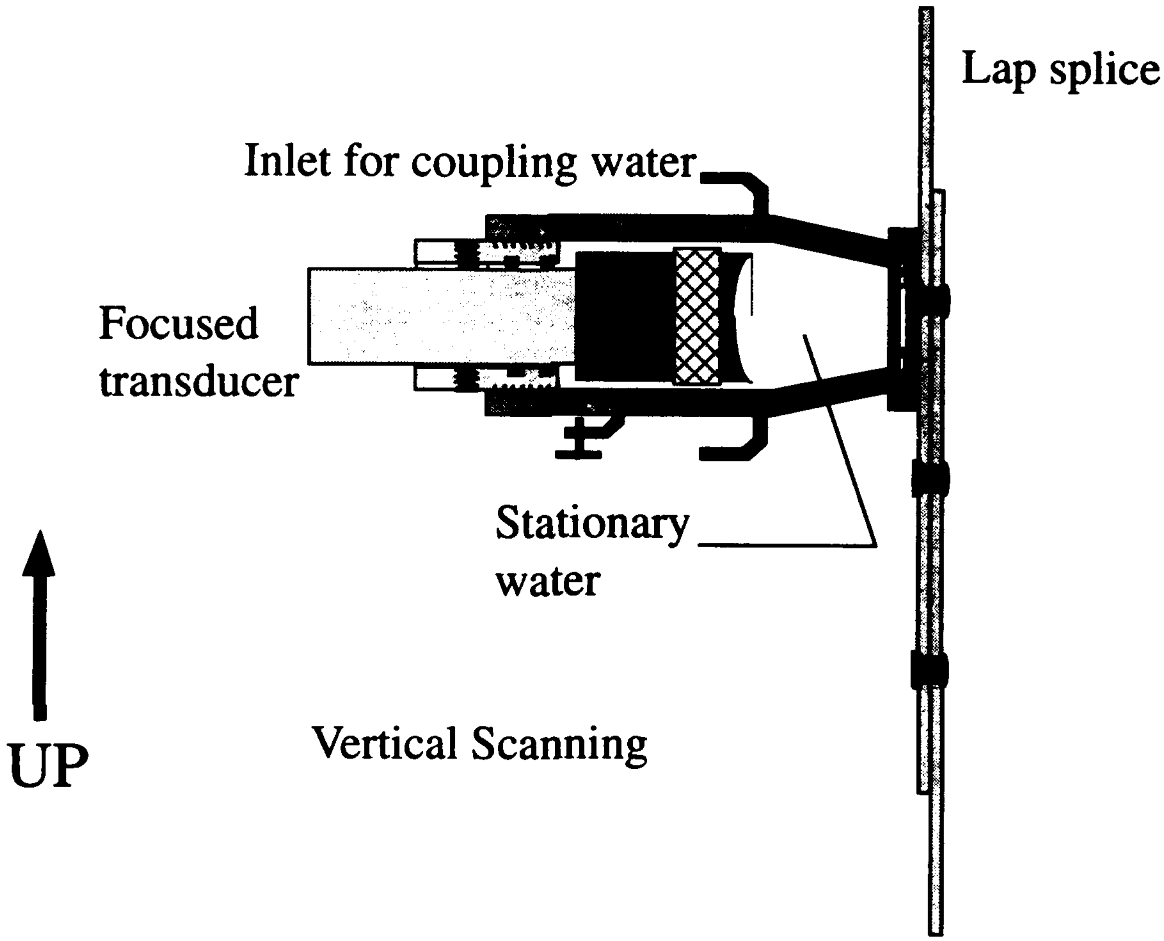

Focused transducer
Transducer housing
Vacuum shroud
Vacuum hose
Membrane
Water pool
Foam water retaining ring
Water inlet tubing
(Coaxial with vacuum hose)
Riveted lap splice
7/7/93

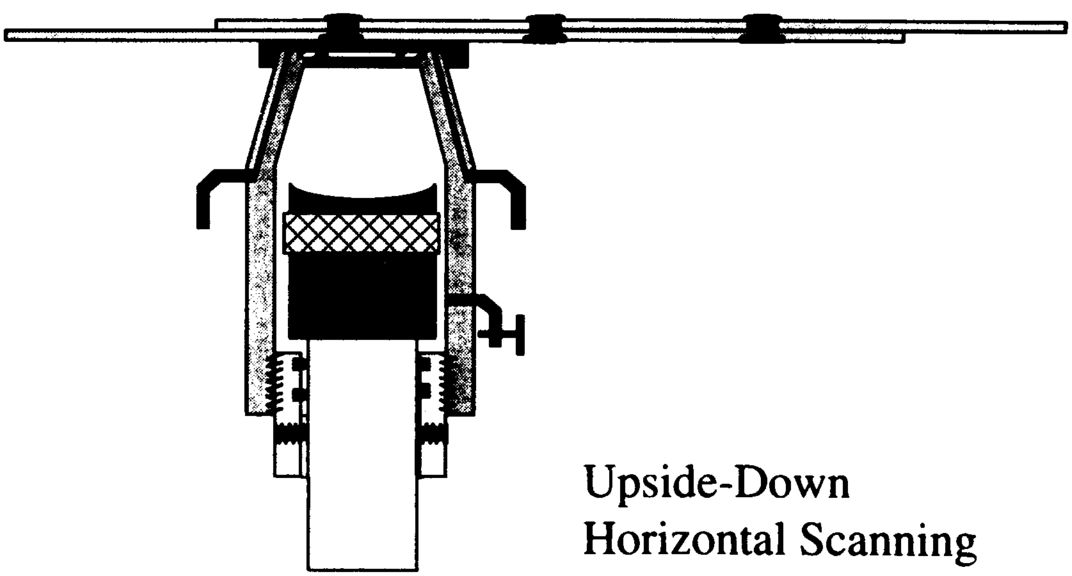
Figure 1

Dripless Bubbler Scanning Orientations

(Vacuum attachment not shown)

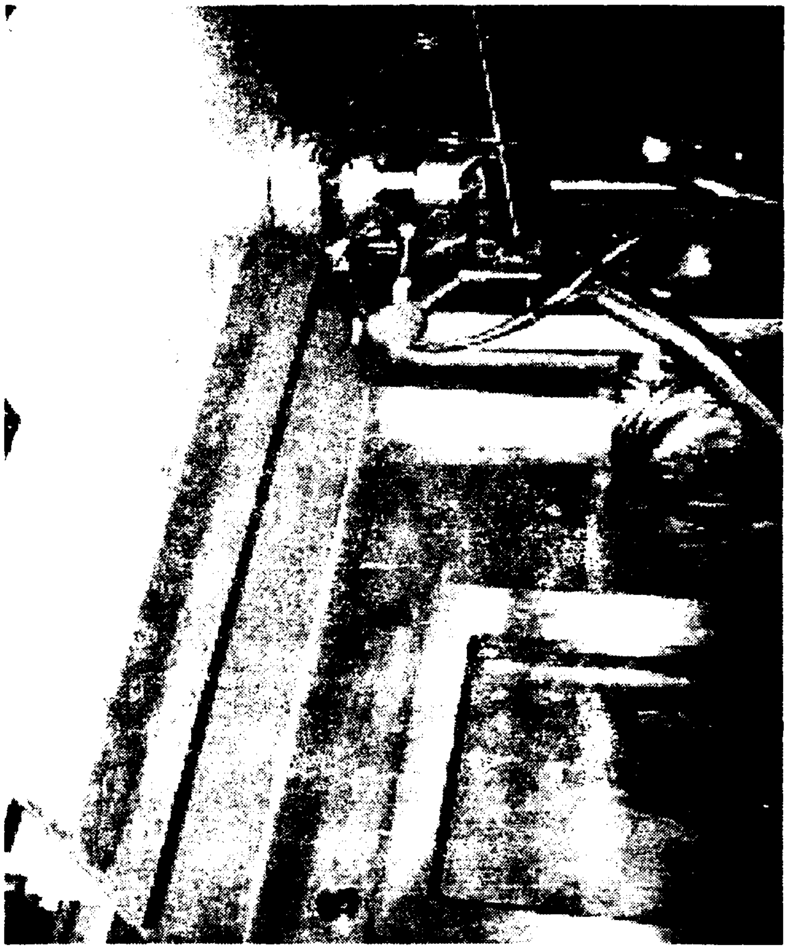


Vertical Scanning



Upside-Down
Horizontal Scanning

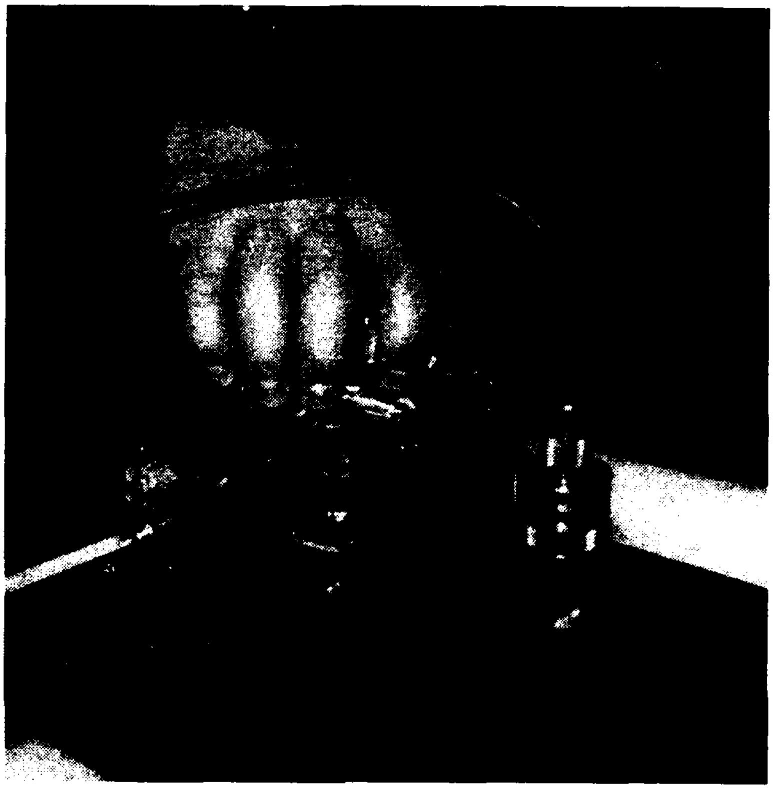
Scanning a vertical Boeing lap splice with "Dripless Bubbler" developed under FAA-CASR



The device allows focused beam ultrasonic C-scans based on amplitude and time of flight for corrosion and disbond detection.

It features a closed-cycle water pump and vacuum and can be operated on vertical or overhead surfaces. Scans can be made over surface protrusions, such as buttonhead rivets.

Dripless Bubbler Combined with MAUS III

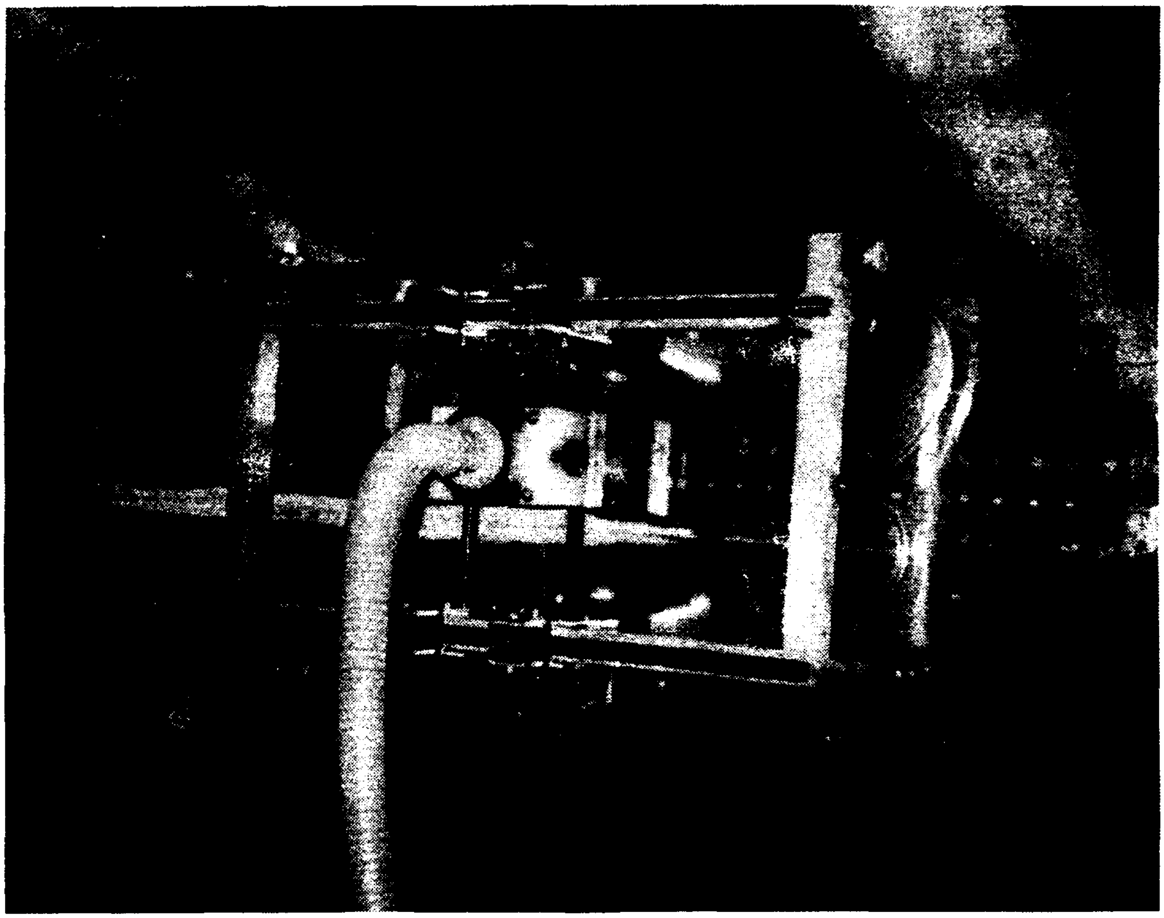


MAUS III sweeps out a band at a time, can follow gradual contour, scans long sections of lap splice continuously, and has multi-mode capability.

Image of corrosion in Boeing #6 sample as obtained by dripless bubbler and MAUS III with 15 MHz, 2" focus transducer. Scan area = 6.5" x 2" Scan time: 6 seconds.

DB+ MAUS III.pg

Scanning of 10'x6' Foster-Miller Panel using Dripless Bubbler Scanning Bridge



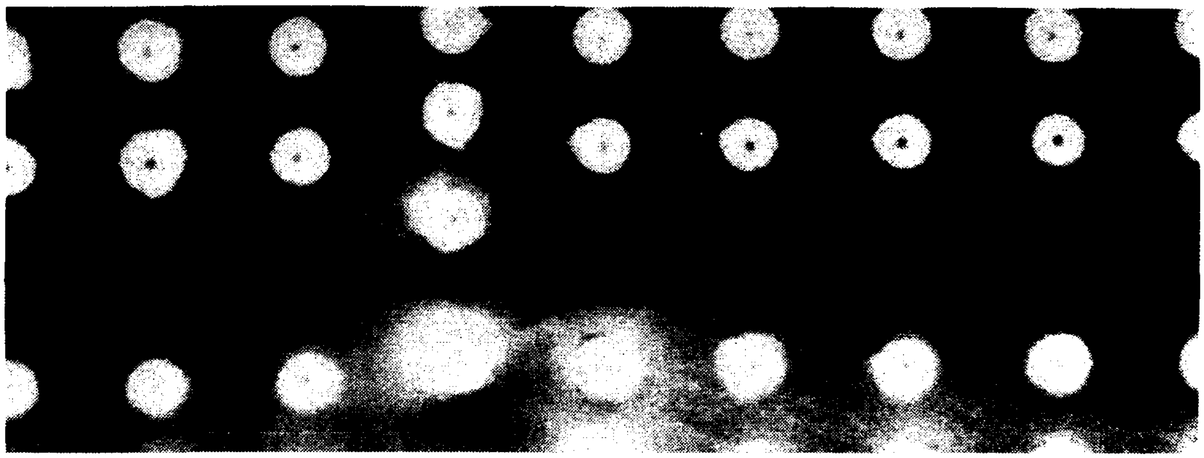
Closed-cycle,water coupled, focused transducer
Center freq. = 1 MHz (using low frequency method)

DB on FM .pg

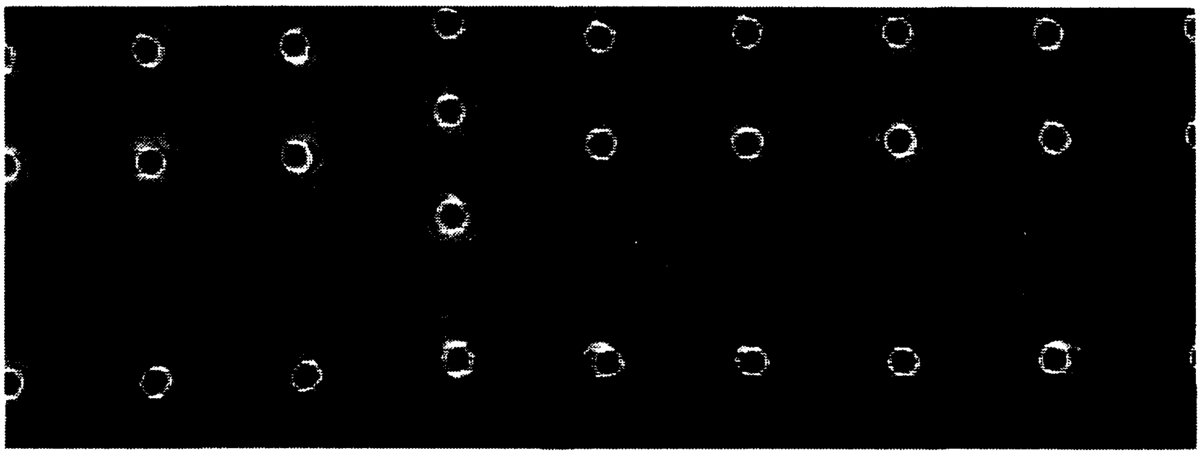
Dripless Bubbler Scan of Foster-Miller Panel
Repair patch with Buttonhead Rivets and Sealant in the Back

Scanned Area = 8" x 3"
1 MHz trasnducer with 1" focus

Amplitude



Time of Flight

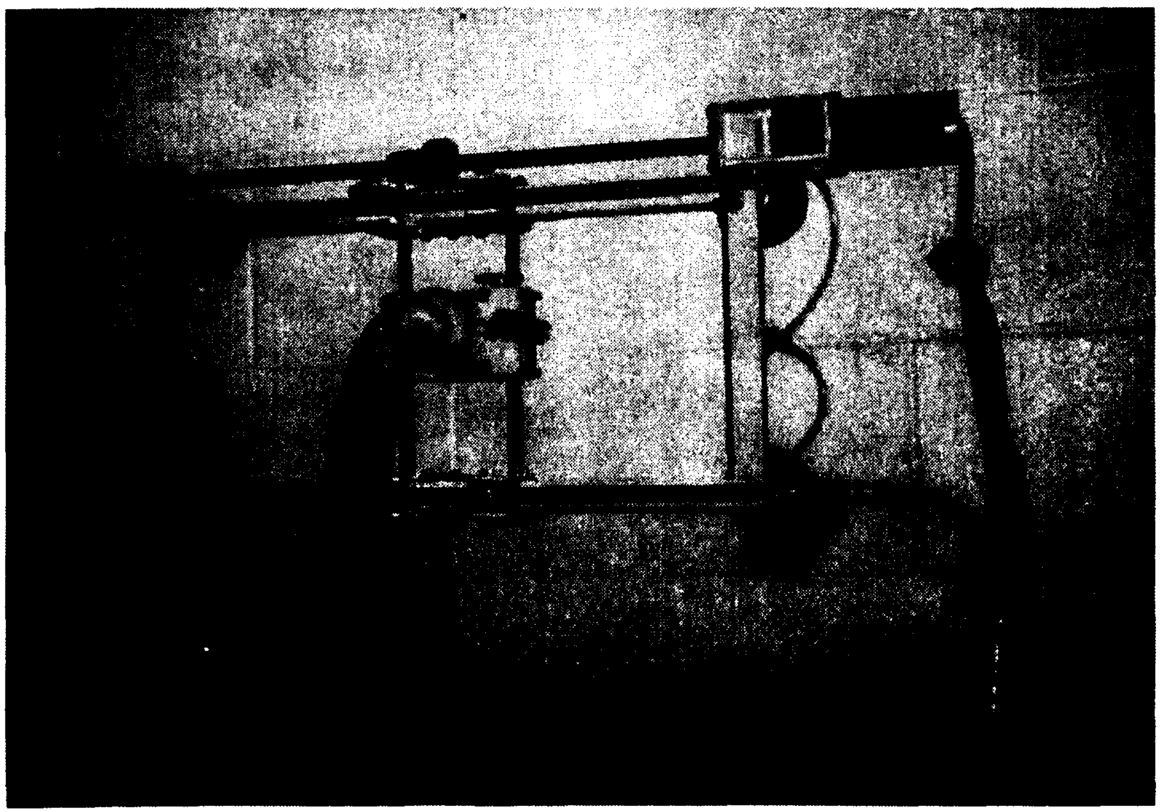


DB/Button.pg gray

Motorized Scanner for Dripless Bubbler

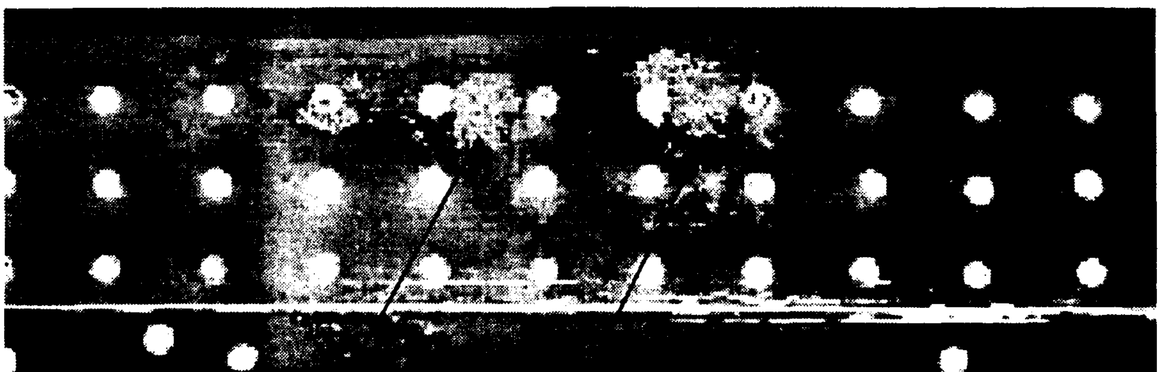
Scanner weighs 18 pounds. Rectangular frame measures 22" x 11"

Held on a painted cinder block wall by compressed air suction cups



3/26/94

Field Demonstration of Dripless Bubbler Scanner on Northwest Airlines Boeing 747 lap splice

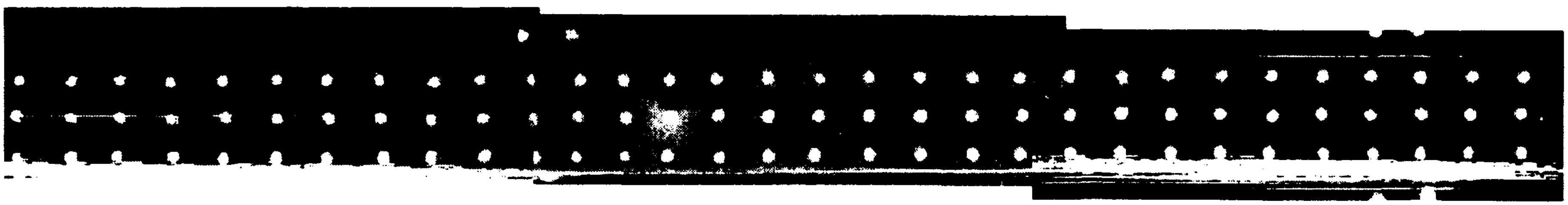


Indication of corrosion near popped rivets
Scanned area 12.5" x 4" @ 15 MHz, focused

Composite C-Scan images of lap splice

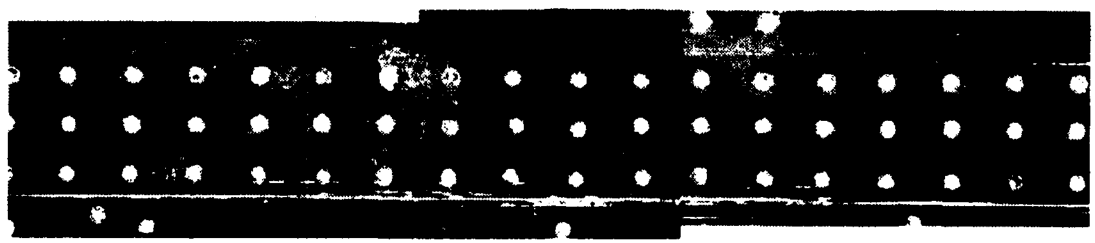
Images acquired using amplitude of the 1st back surface echo in the top aluminum skin with a 15 MHz focused immersion transducer and the Dripless Bubbler

Sta. 1940 Sta. 1920



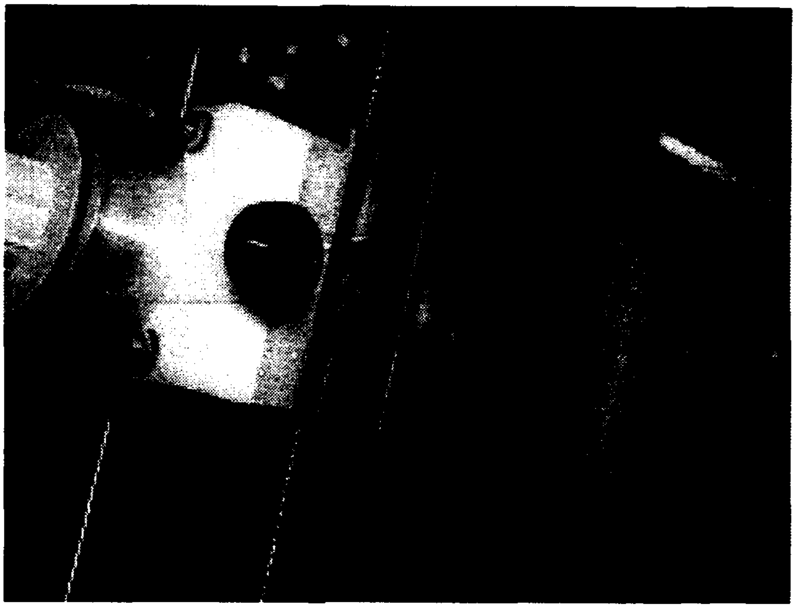
Sta. 1920

Sta. 1900



Images aquired on 3/31/94 at Northwest Airlines (Minneapolis, MN)
Boeing 747-200 lap splice (stringer: 23R, station: 1900-1960)
Images shown individually contrast enhanced
Transducer: 15.0 MHz, 0.5 in dia., 2.0 in focal length (water)
Scan area: 12.5 x 4.0 in (32 x 10.2 cm)
Scan step size: 25 mils
Scan time: 15 minutes each image
Files: F747-6.CS1.TIFF, F747-7.CS1.TIFF, F747-8.CS1.TIFF, F747-9.CS1.TIFF, F747-10.CS1.TIFF

Field Trial on Boeing 747 at Northwest Airlines



Motorized Scanner with Dripless Bubbler
Notice top row of 1/2" dia. buttonhead rivets

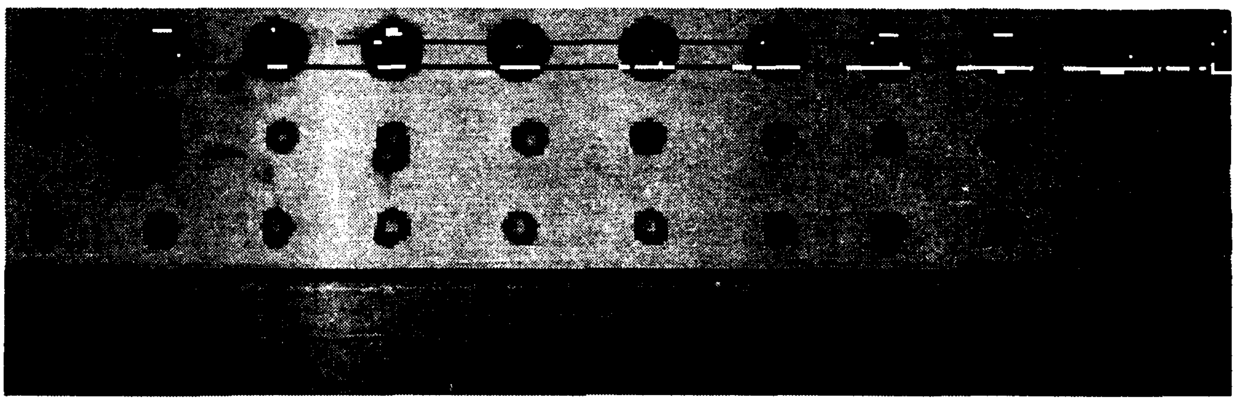
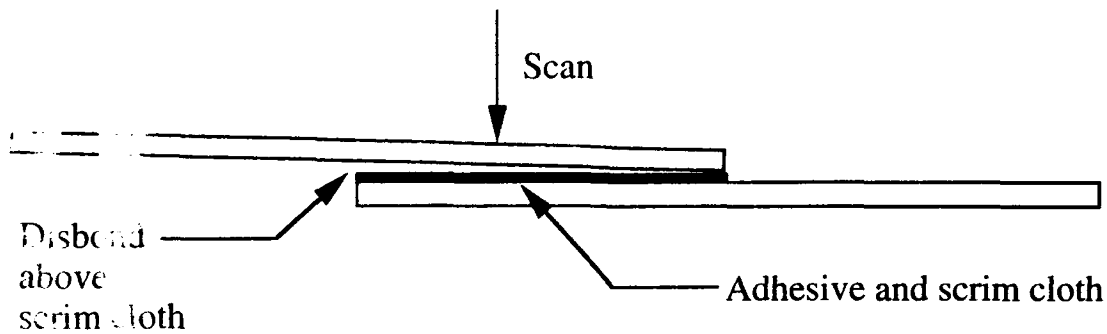


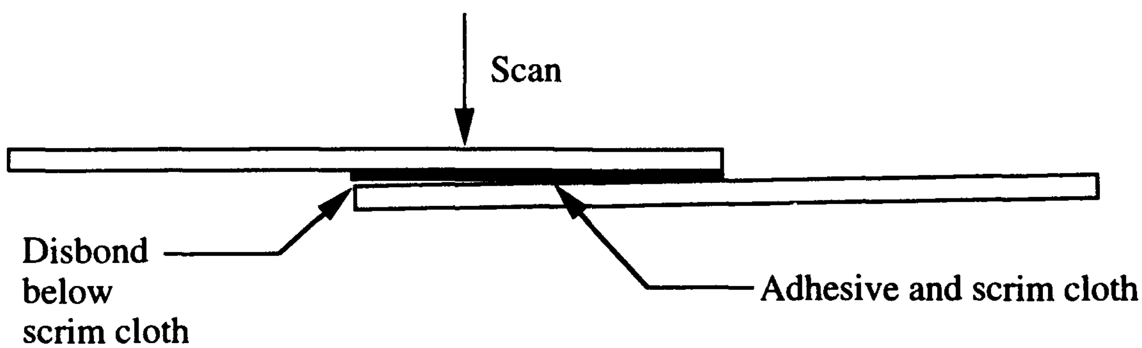
Image acquired with 1 MHz, 1" focus probe
Scan area = 12.5" x 4", step size 0.025"

Disbond Detection Above and Below Scrim Cloth

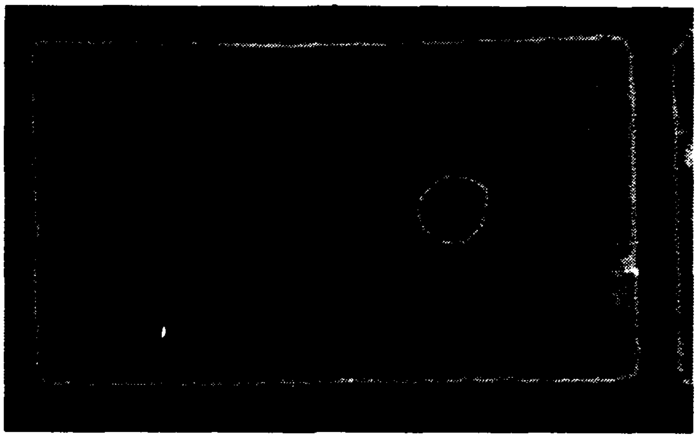
(1) Both low frequency and high frequency scans revealed disbonded area



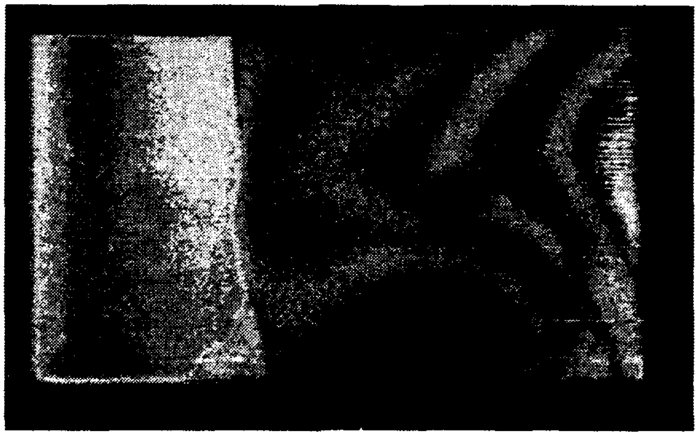
(2) Low Frequency scan showed disbonded area, high frequency scan unsuccessful



Comparison of Low and High Freq C-Scans of Disbond Above Scrim Cloth



1 MHz, Unresolved Echo



15 MHz, 2nd Backwall Echo

Sample: Adhesively bonded Al lap splice with fatigue-induced disbond

Scan size: 5.2" x 3.2", step = 0.02"

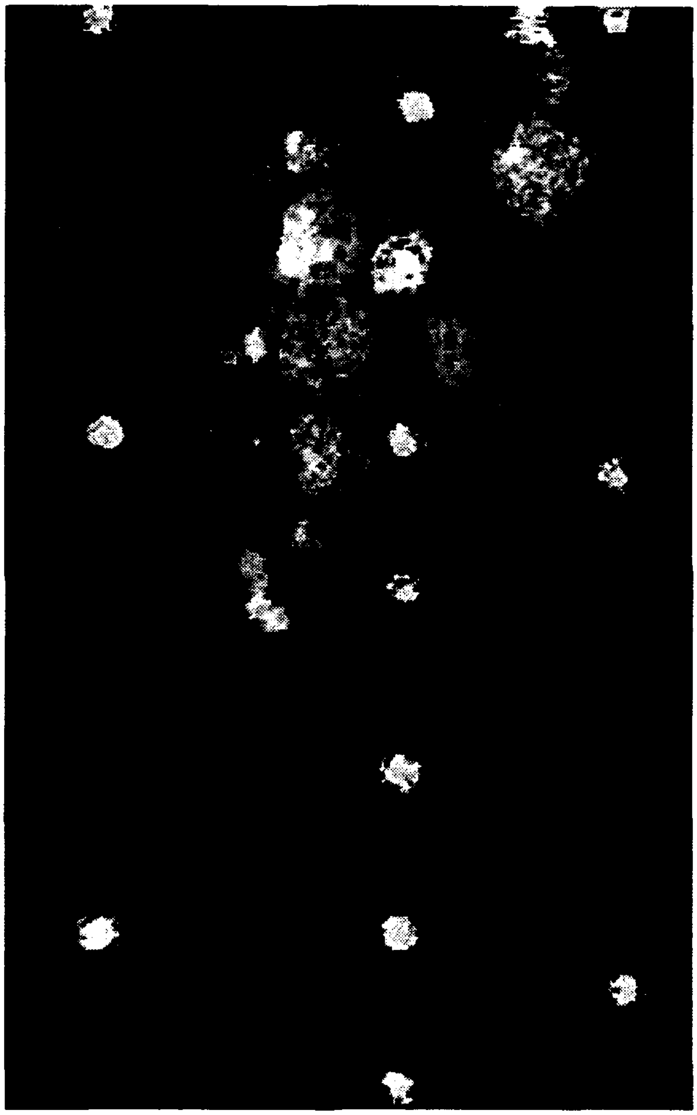
Files: TU6-2R2.CS0, TU6-2R5.CS0

Comparison of disbond size revealed by three NDI methods

Disbond lengths at three locations of a lap splice as determined by three different NDI methods. Optically measured lengths (at edges only) during fatigue testing are also listed.

	Optical	Ultrasound	Thermal wave	ESPI
Top edge	45 mm	47 mm	45 mm	42 mm
Middle	-----	49 mm	34 mm	43 mm
Bottom edge	50 mm	52 mm	47 mm	44 mm

Ultrasonic Time-of-Flight Scan of Corrosion in Boeing Sample VI



Pulse-echo using 15 MHz, 0.5" diam., 3" focus probe
Scan area = 5" x 8", step size = 0.025"
Circles of equal size are rivets, light gray regions are corrosion

File Name BC-VI-2.CS8

Compare Handscan with Motorized Scan
Boeing Corrosion Sample VI

Motorized scan
TOF of 2nd gate
1 MHz, 2"focus
3.3"x 3.5" scan

SONIX handscan
(with aid of tracks)
TOF of 2nd gate
3.3" x 3.5" scan
1MHz, 1" focus

Task 2: Ultrasonic Characterization of Adhesive Bonds

Future Directions:

- Test dripless bubbler scanning bridge built at CASR on 10' x 6' Foster Miller panel. Make necessary modifications to the design and operation of the device.
- Field demonstration of dripless bubbler at airlines. Field demonstration on B737 testbed at AANC (scheduled).
- Pursue Technology Transition activities.
- Broaden scope of investigation to include composite materials and structures.

SHEAROGRAPHY FOR AGING AIRCRAFT

Dave Galella
FAA Technical Center
April 4-8, 1994

SHEAROGRAPHY FOR AGING AIRCRAFT

FAATC and Volpe TSC Conducted Three Shearography Tests

Foster-Miller Panels, DOT/FAA/CT-TN92/26
B-737, DOT/FAA/CT-TN92/19
DHC-7, DOT/FAA/CT-TN92/39

Results Showed Shearography *Capable of Finding* Disbonds *in* Fuselage Laps and Bonded Skin Doublers

Based on These Tests, Laser Technology, Inc (LTI) Applied to the Philadelphia Flight Standards Office (FSDO-17) to become an FAA Certified Repair Station with a Limited Rating for Shearography NDT

LTI would provide shearography as a subcontracted service to other repair stations

Concurrently,

LTI Applied to the Seattle Aircraft Certification Office for an Alternate Means of Compliance for Inspection of B-727 Airplanes called for in ADs 90-21-10 and 90-26-09

The intention is to externally use shearography on an annual basis to extend the period between the close internal visual inspections from 48 to 72 months for corrosion and disbonding in the circumferential splice doublers

Market interest of 15 customers with 75 aircraft in Executive Interior Configuration.

ACO Requirements

1. Complete and submit the process specification and load application

2. Perform "blind tests" on panels with known defects to establish reliability of shearography

3. Perform blind test on a Boeing 727 or 737 to establish a comparison between shearography and known techniques including internal close visual inspections

4. Compare the external shearography results to the internal visual inspections mandated by the ADs on each customer aircraft and baseline each aircraft for comparison with the annual interim inspections

5. Based on data from 2, 3, and 4 establish probability of detection curves.

FAA TECH CENTER SUPPORT

FAATC/TSC have assisted FSDO-17 with the approval of LTI's Repair Station Manual and Process Specification

Tests are being planned at the FAA-AANC after the 737 baselining which should satisfy ACO requirements 2 and 3.

REASONS FOR SUPPORT

Shearography is a quick, non-contact, inspection technique with potential applications for both metal and composites

There is a customer (airline) pull for the technology

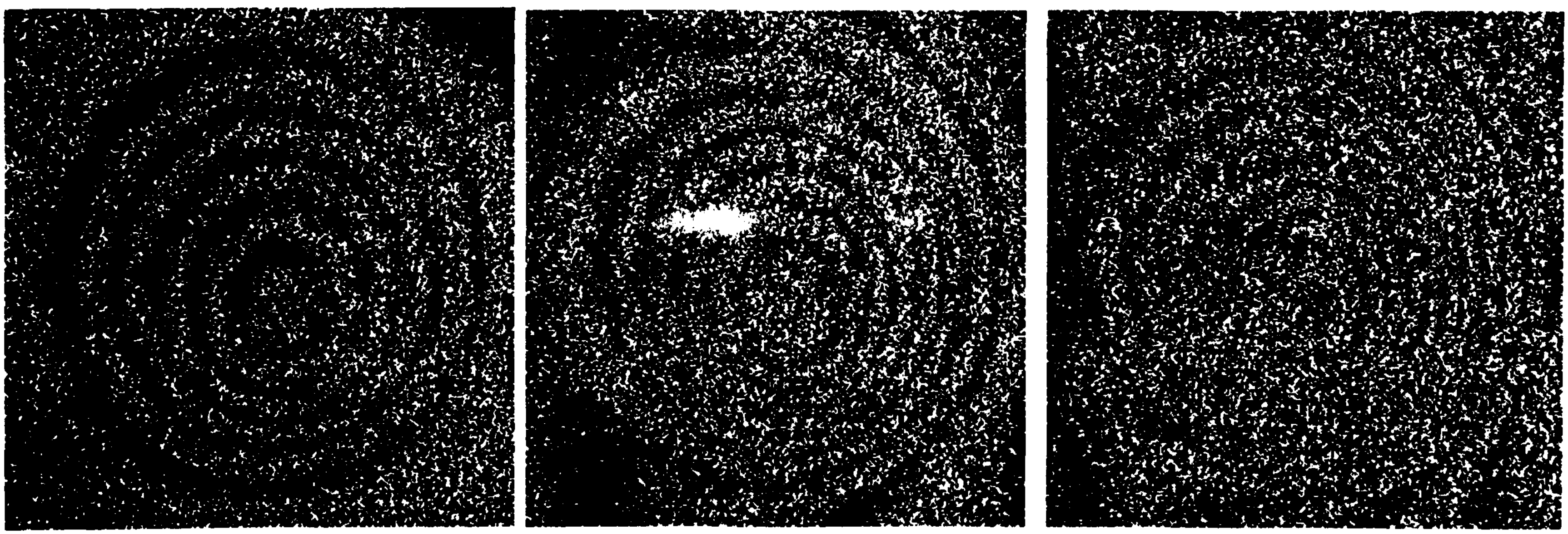
LTI has established a licensing agreement with Northwestern University to incorporate FAA funded research into field units
and LTI is assisting New Mexico State University with the testing of its coherent optical model

PROJECT:	TECHNIQUES FOR FLAW DETECTION
TASK:	OPTICAL INTERFEROMETRY
PRINCIPAL INVESTIGATOR:	SRIDHAR KRISHNASWAMY
RESEARCH FELLOWS:	BRUNO F. POUET THOMAS C. CHATTERS
FAA SPONSOR:	RICHARD YARGES
FAA MONITOR:	DAVE GALELLA
INDUSTRIAL INTERACTION:	LASER TECHNOLOGY INC

OBJECTIVE

TO DEVELOP ROBUST, NOISE INSENSITIVE OPTICAL NDE SYSTEMS FOR NON-CONTACT LARGE AREA INSPECTION OF HIDDEN DAMAGE IN AIRCRAFT STRUCTURES.

PRIMARY DRAWBACK OF CONVENTIONAL SHEAROGRAPHY / ESPI



DEFECT SIGNATURE DISTORTION / LOSS DUE TO AMBIENT NOISE

ACCOMPLISHMENTS TO DATE:

- LABORATORY PROTOTYPE DEVICE DEMONSTRATED
  (papers: Optical Engineering, Journal of NDE)

- VISIBILITY ANALYSIS PERFORMED AND EXPERIMENTALLY VERIFIED SHOWING IMPROVED PERFORMANCE OF THE NEW METHOD
  (paper: Applied Optics)

- LICENSING AGREEMENT WITH LASER TECHNOLOGY INC SIGNED FOR TRANSFER OF TECHNOLOGY

OBJECTIVE

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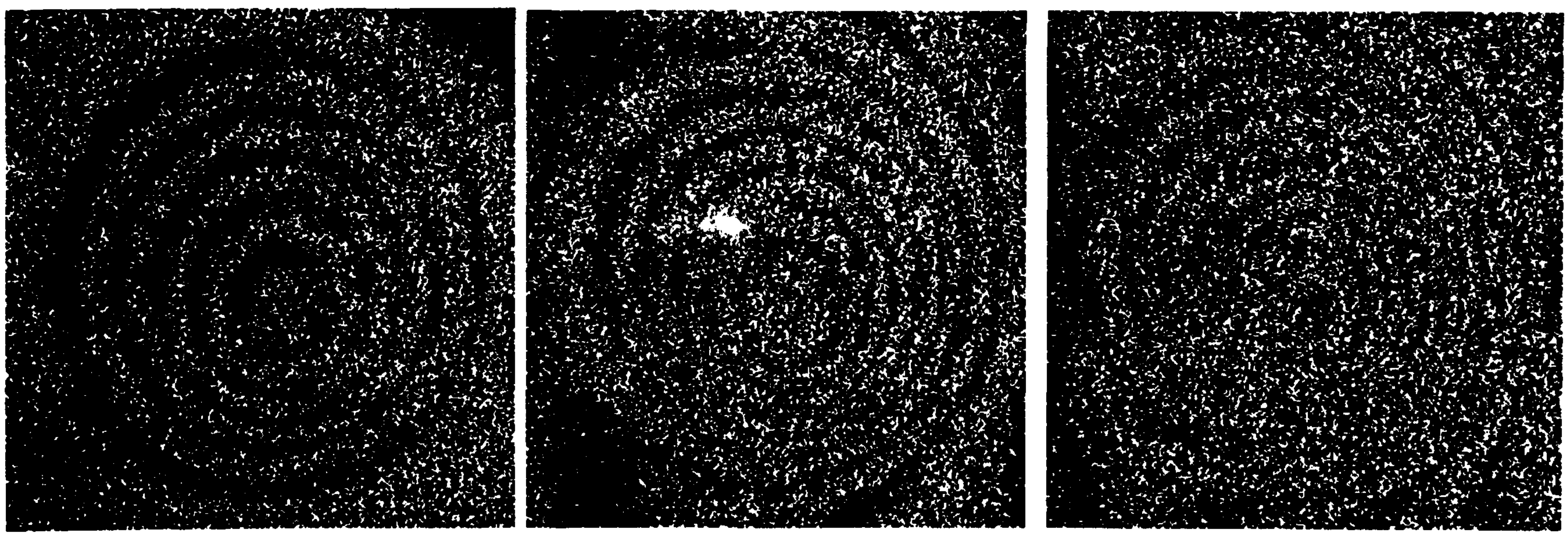

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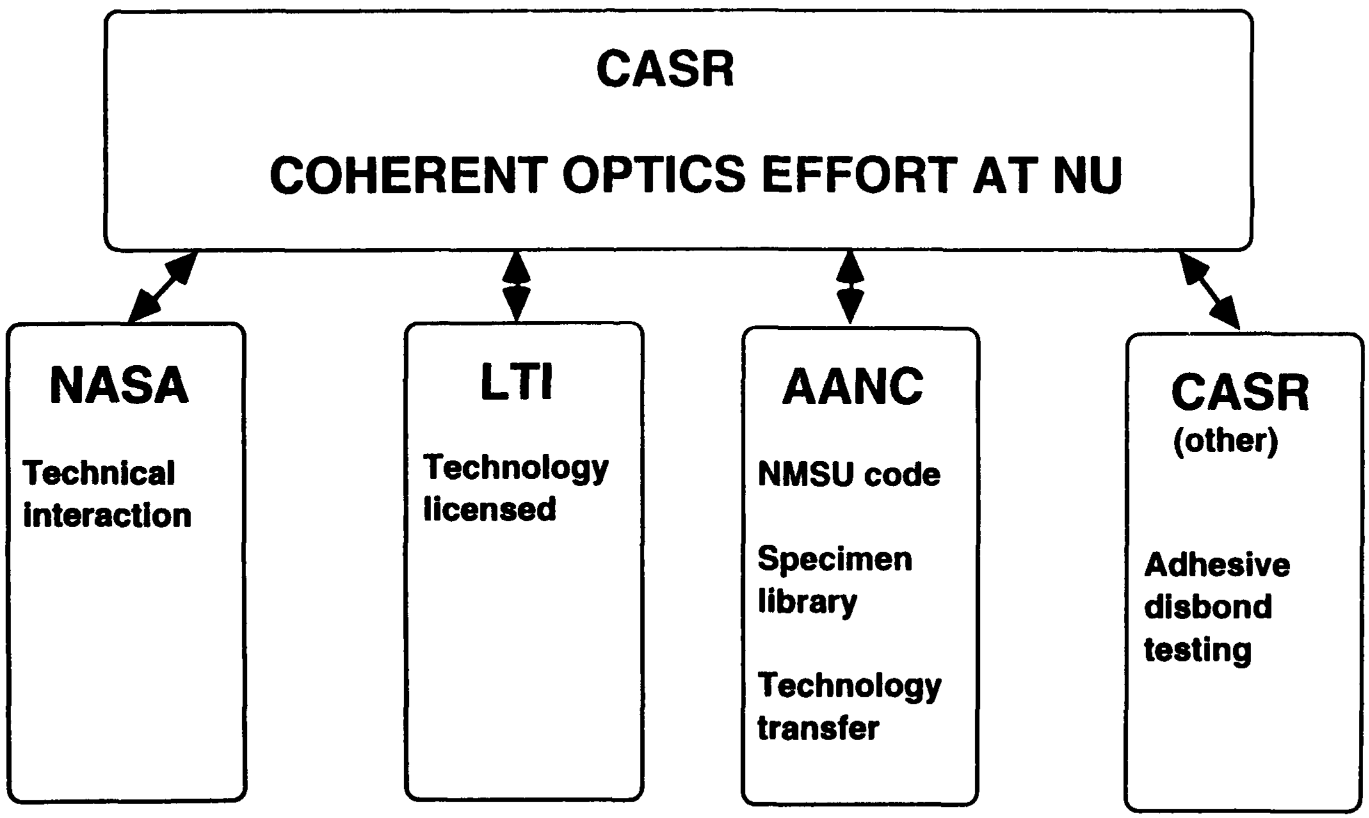
PROGRAM INTERACTION



EFFECT OF AMBIENT NOISE ON SPECKLE INTERFEROMETRY

SOURCE	TYPE	EFFECT
OBJECT DRIFT (eg: settling of landing gear)	SLOW LARGE AMPLITUDE	DECORRELATION
STRUCTURAL VIBRATIONS (eg: machinery)	LOW FREQUENCY MEDIUM AMPLITUDE	DECORRELATION & PHASE SHIFTS
THERMAL NOISE (eg: air-conditioning ducts)	HIGH FREQUENCY SMALL AMPLITUDE	PHASE SHIFTS

- DECORRELATION ⇒ SIGNATURE LOSS
- PHASE SHIFTS ⇒ SIGNATURE DISTORTION

SYSTEMS UNDER DEVELOPMENT

OPTICS:

First Enhancement: (Solves signature loss problem)

- REFERENCE_UPDATING_SUBTRACTIVE_ESPI
- REFERENCE_UPDATING_SUBTRACTIVE_SHEAROGRAPHY

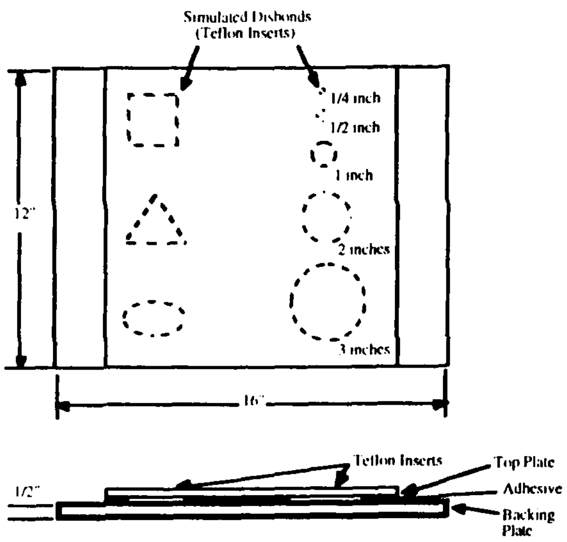
Second Enhancement: (Solves signature distortion problem)

- ADDITIVE_SUBTRACTIVE_PHASE_MODULATED_ESPI
- ADDITIVE_SUBTRACTIVE_PHASE_MODULATED_SHEAROGRAPHY

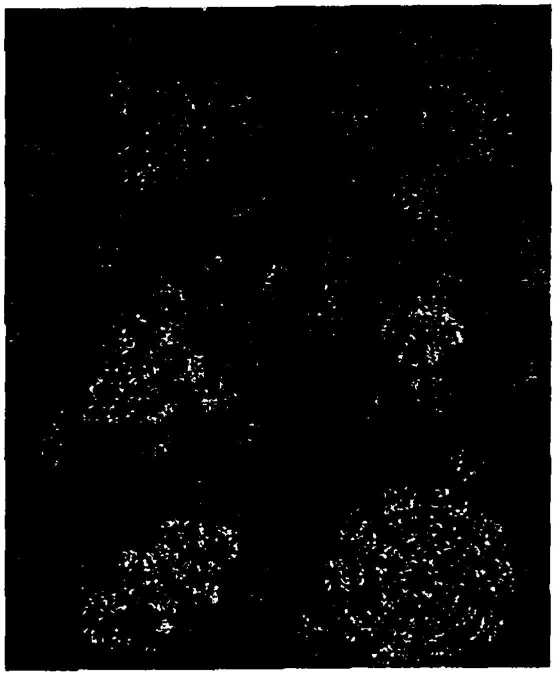
STRESSING:

- SYNCHRONIZED ACOUSTIC STRESSING
- SYNCHRONIZED PRESSURE STRESSING

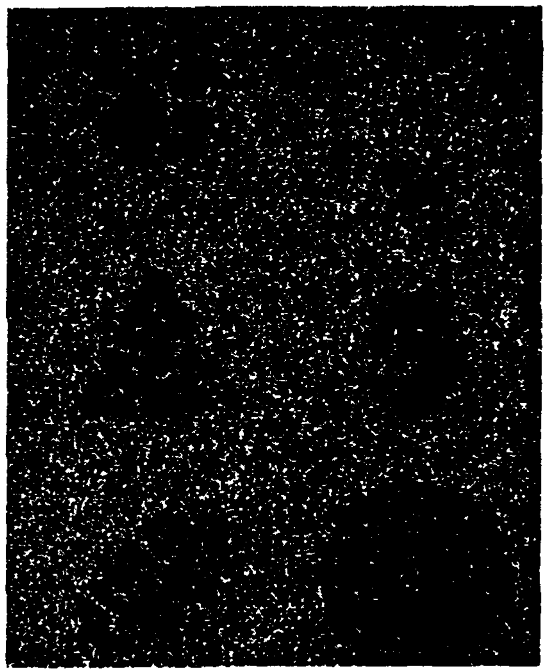
DISBOND DETECTION USING ASPM-ESPI / ACOUSTIC STRESSING



SPECIMEN GEOMETRY



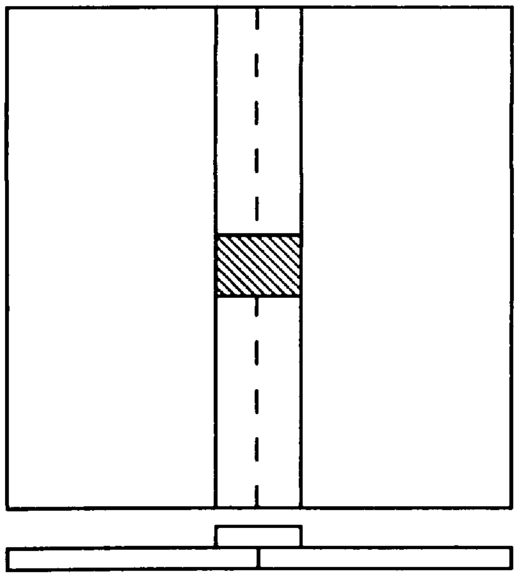
CONVENTIONAL ESPI



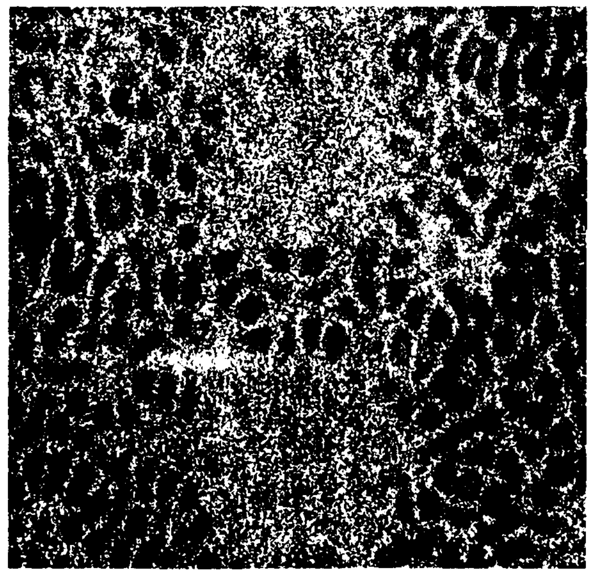
ASPM-ESPI

•Note that in the conventional technique some of the disbonds are not detected due to ambient noise.

ASPM-ESPI DETECTION OF DISBOND IN A SPLICE JOINT



SPECIMEN GEOMETRY

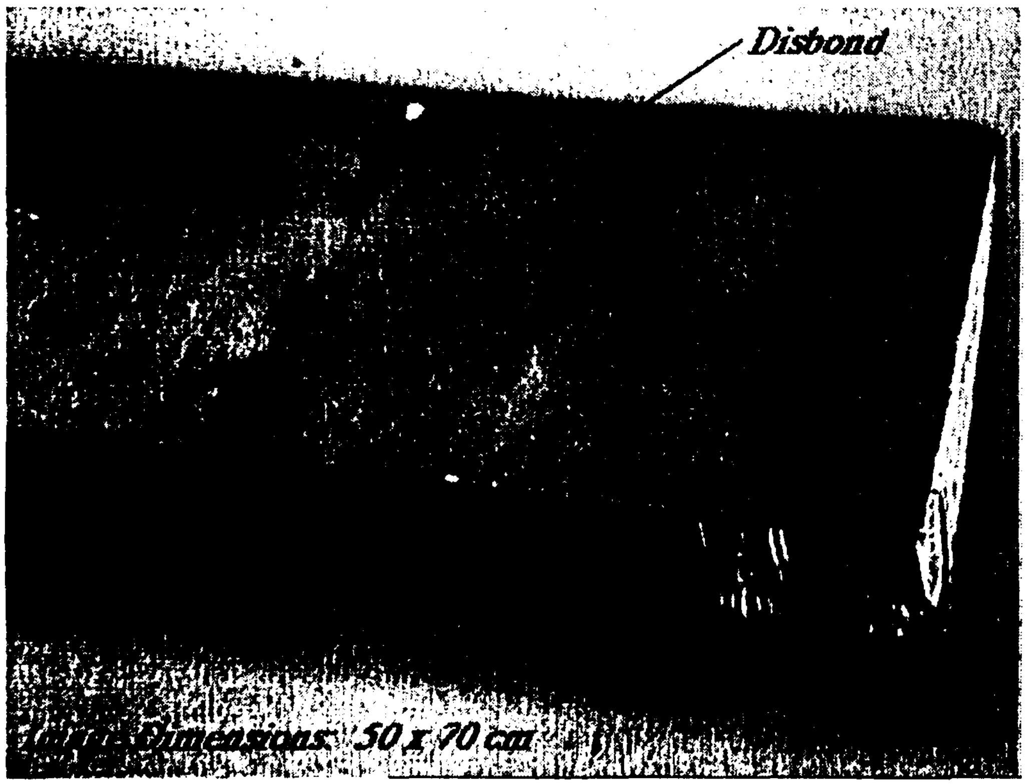


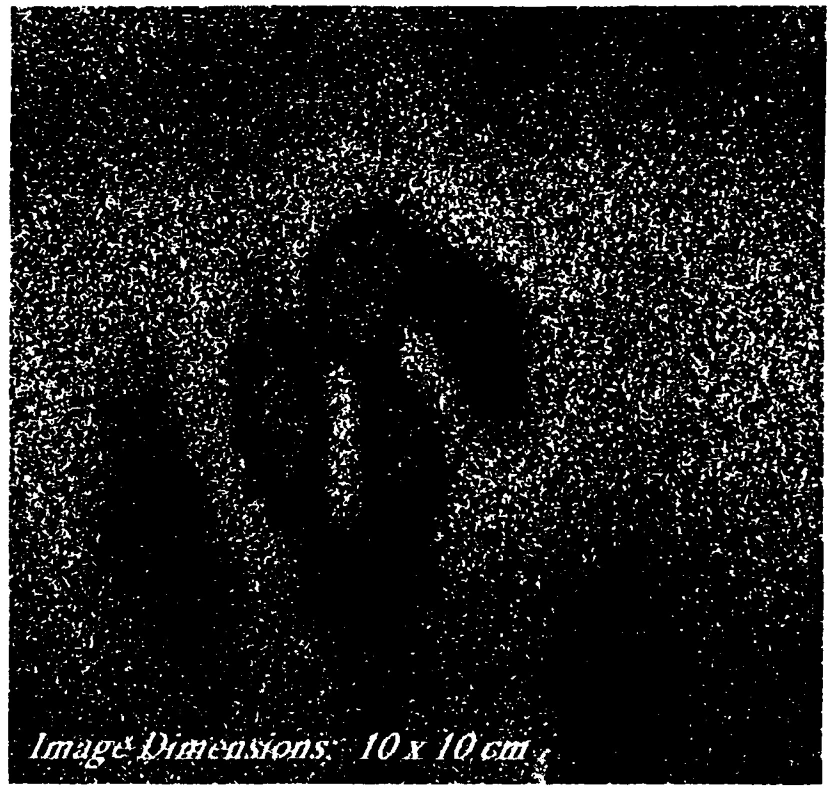
ACOUSTIC STRESSING

PRESSURE STRESSING

FAA - CENTER FOR AVIATION SYSTEMS RELIABILITY

INSPECTION OF COMMERCIAL AIRCRAFT AILERON



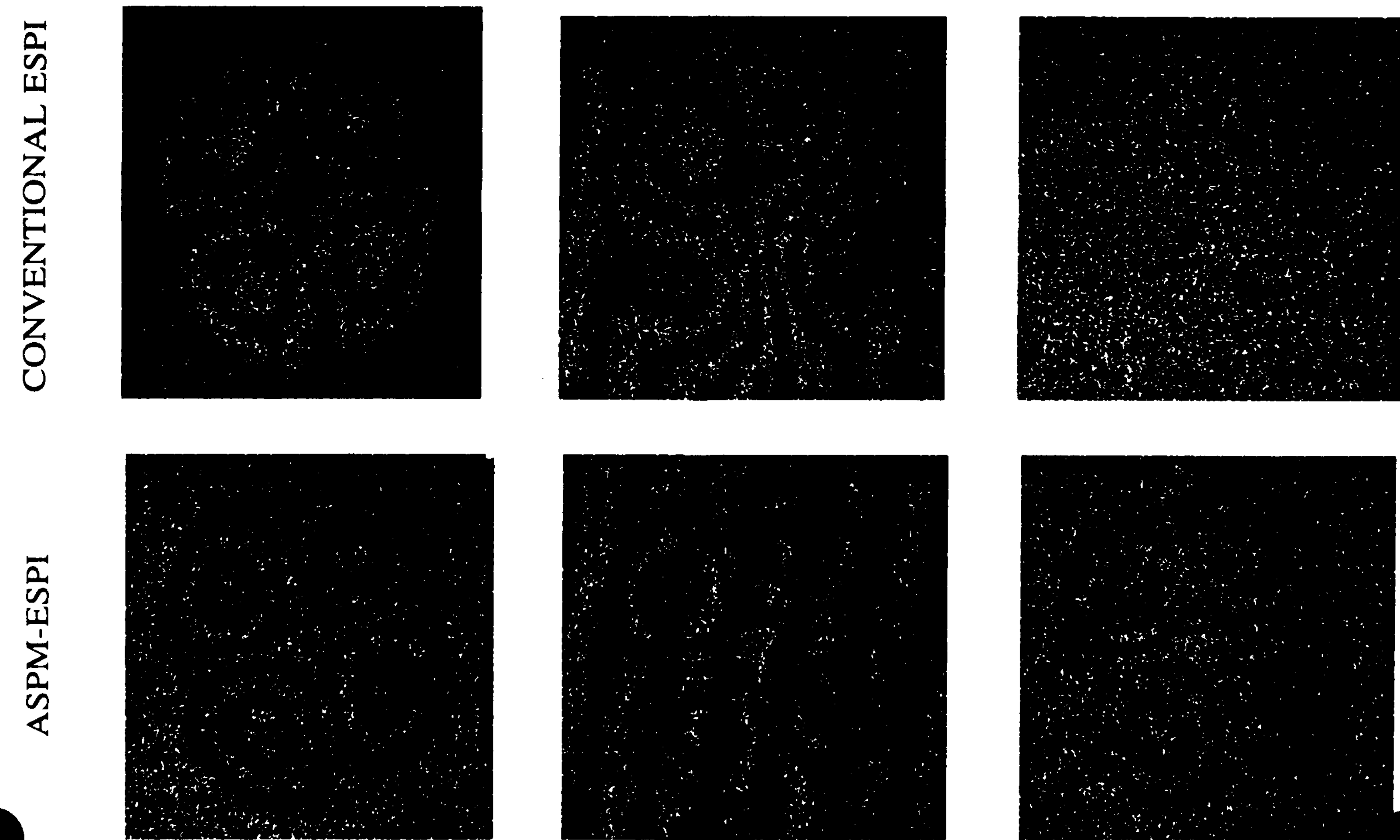


PRODUCTS

Products arising out of this project so far include technology transfer and refereed publications:

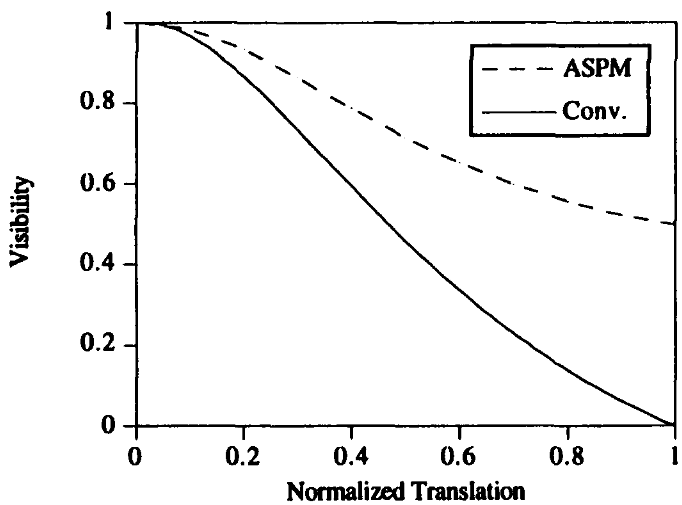
- LICENSING AGREEMENT WITH LASER TECHNOLOGY SIGNED.
- THREE JOURNAL PUBLICATIONS IN PRINT:
  (Optical Engineering; Journal of NDE; Applied Optics).
- ONE MORE JOURNAL PUBLICATION IN REVIEW:
  (Experimental Mechanics).
- SIX CONFERENCE PUBLICATIONS:
  (QNDE Proceedings; SPIE Proceedings)

STUDY OF FRINGE VISIBILITY WITH TRANSLATION-INDUCED DECORRELATION

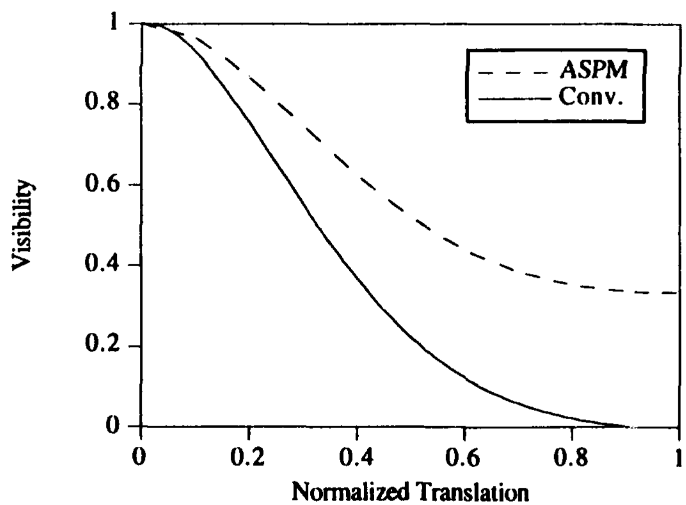


VISIBILITY COMPARISON

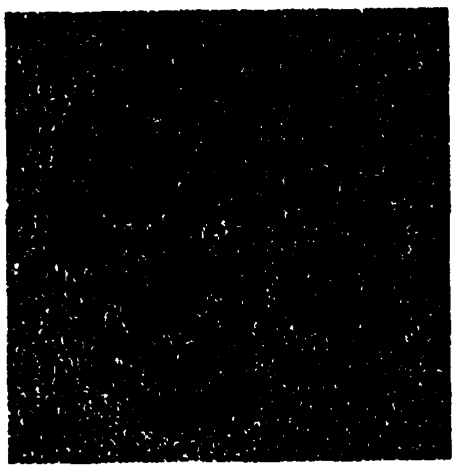
ESPI: ASPM AND CONVENTIONAL



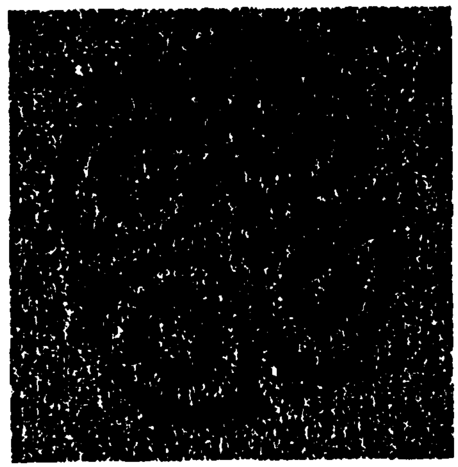
SHEAROGRAPHY: ASPM AND CONVENTIONAL



IMPROVEMENT OF ASPM-ESPI FRINGE VISIBILITY BY ADJUSTMENT OF THE BEAM RATIO



X = 1.0



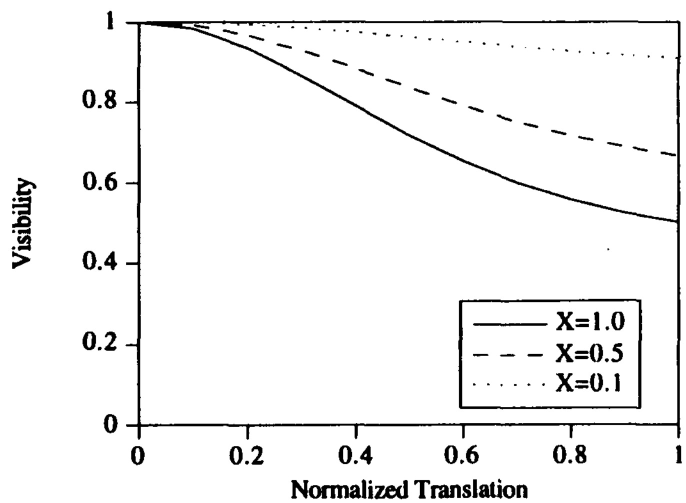
X = 0.5

X = 0.1

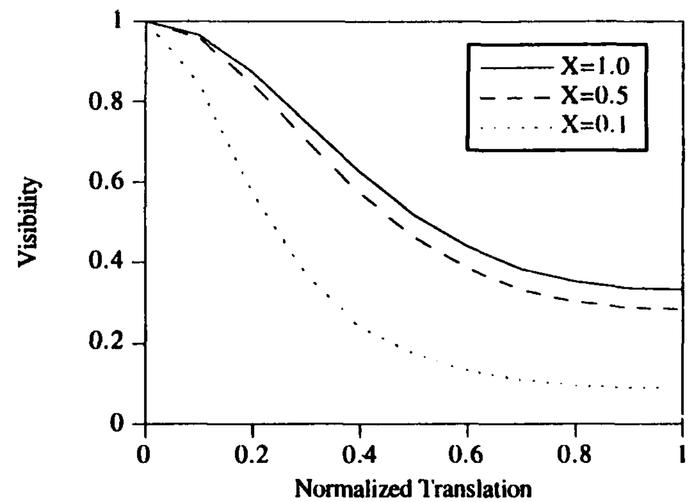
$$X = \frac{\text{OBJECT BEAM INTENSITY}}{\text{REFERENCE BEAM INTENSITY}}$$

EFFECT OF BEAM RATIO ON VISIBILITY

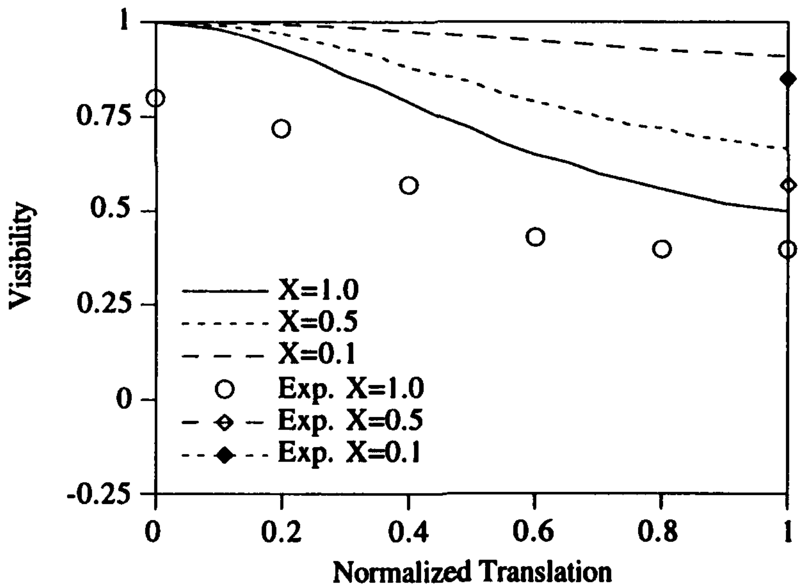
ASPM-ESPI



ASPM-SHEAROGRAPHY



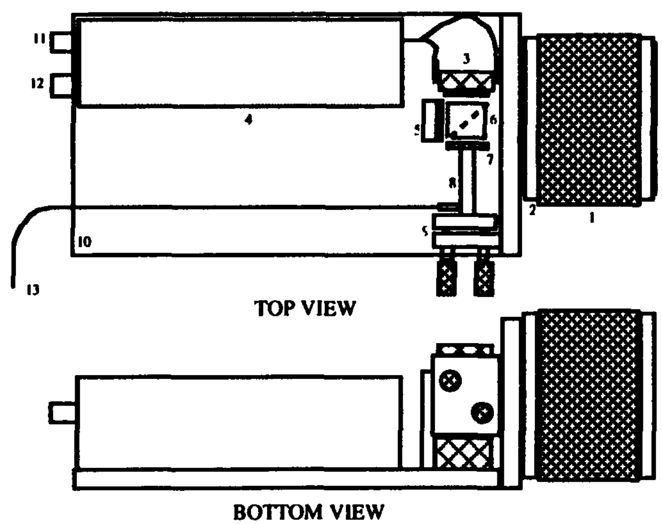
EXPERIMENTAL AND ANALYTICAL RESULTS



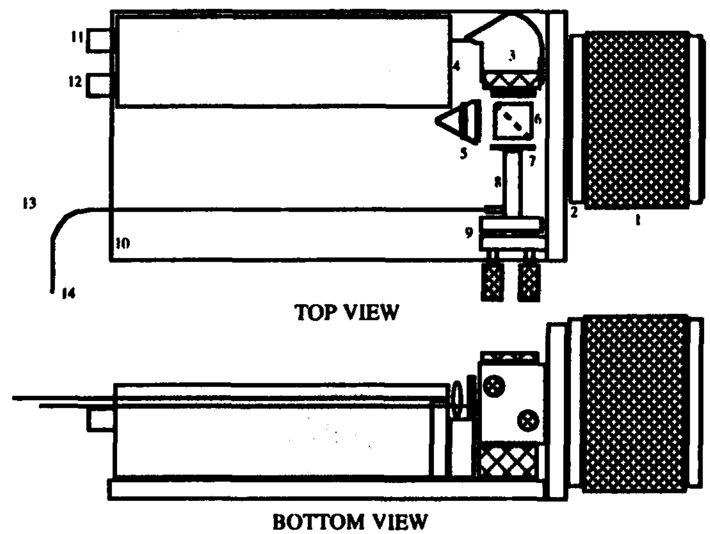
VISIBILITY CONCLUSIONS

- ASPM TECHNIQUE PROVIDES IMPROVED NOISE REDUCTION.
- ANALYTICAL MODEL SUPPORTS EXPERIMENTAL RESULTS.
- RECOMMENDED OPTICAL NDE METHOD --> ASPM-ESPI.
    - ASPM-ESPI MAINTAINS A HIGHER VISIBILITY AT TOTAL DECORRELATION.
    - ASPM-SHEAROGRAPHY DECORRELATES FASTER WITH TRANSLATION.
    - VISIBILITY OF ASPM-ESPI CAN BE BOOSTED BY ADJUSTING BEAM RATIO EVEN UNDER CONDITIONS OF TOTAL DECORRELATION.

FUTURE WORK: MINIATURE ASPM-SHEAROGRAPHY/ESPI CAMERA



ASPM-SHEAROGRAPHY MODE



ASPM-ESPI MODE

FUTURE WORK

- DEVELOPMENT OF FIELD PROTOTYPE DEVICE.
- FIELD VALIDATION AT AANC/SANDIA.
- CONTINUED INTERACTION WITH LASER TECHNOLOGY INC IN FIELD VALIDATION PROCESS.

DELIVERABLES

- INTERIM REPORT DETAILING DEVELOPMENT OF TEST BED WAS DELIVERED TO THE FAA IN JANUARY 1993.
- FINAL REPORT DETAILING SPECIFICATIONS OF THE PROTOTYPE OPTICAL NDE DEVICE DUE FEBRUARY 1995.

Coherent Optics Based inspection Requirements Analysis

C O B R A

Report by Joseph Genin
Michael Valley
Wei Xu

GOALS

Enhance coherent optical techniques to provide cost effective, reliable, user friendly methods for aircraft inspection and repair design and inspection.

New Mexico State University

APPROACH

Develop a user friendly computer program that provides the capability to:

- Simulate an inspection process (training)
- Design an optimal inspection process for a given flaw or repair
- Provide results in a non-interpretive format

APPROACH Continued

- Acquire true quantitative displacement and strain information

  This year we shall demonstrate that surface strain and/or displacement mapping can be used to assess the effect of riveted repairs on the parent structure and bond integrity issues.

STATUS REPORT

Initiated development of code in 1993.

Preliminary version delivered in January 1994.

Current Capabilities:

- ESPI and Shearography simulation
- Fringe pattern and inspection sensitivity data
- Single and dual illumination beams
- Equation based inspection surfaces

STATUS REPORT

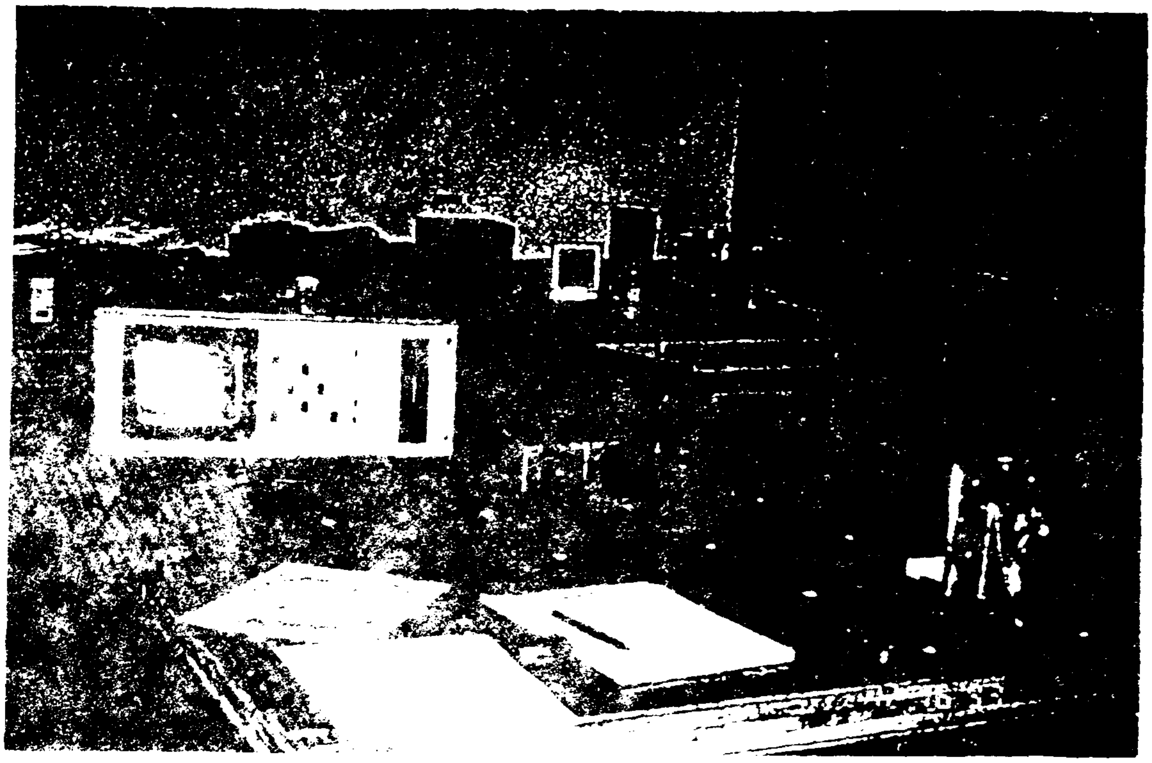
Current Capabilities Continued:

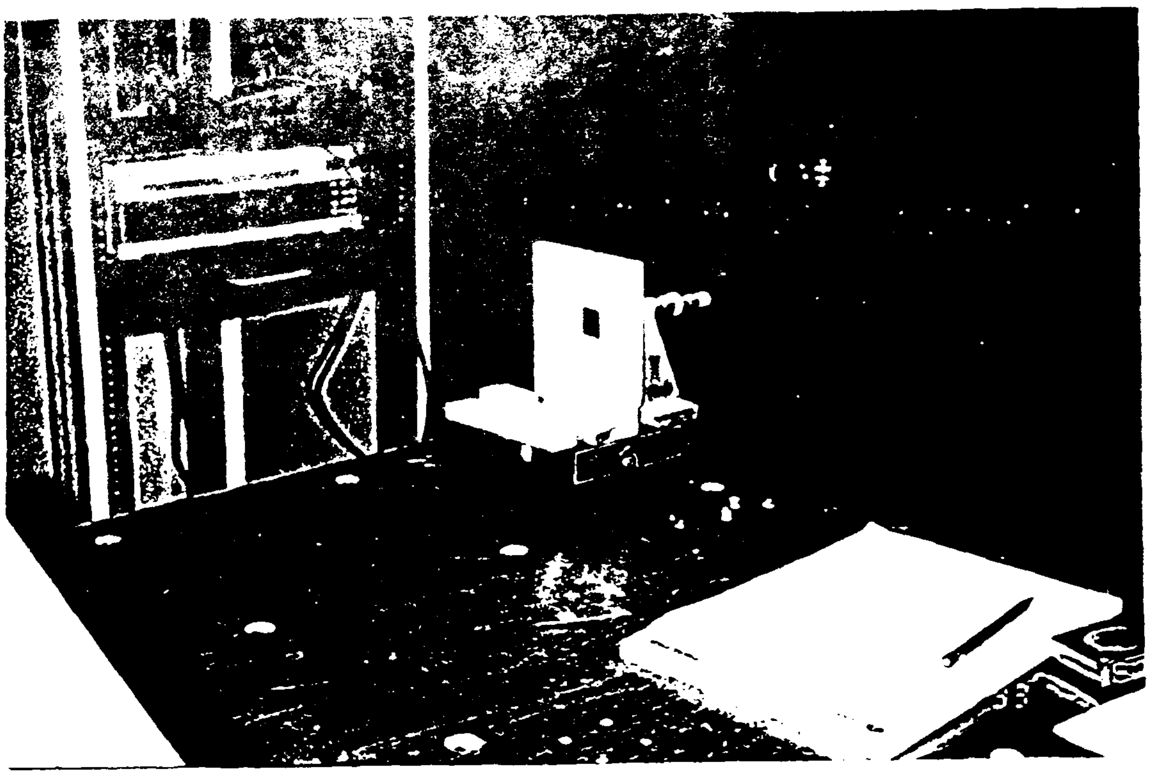
- Loading - any combination of uniform displacements, deformations and rotations

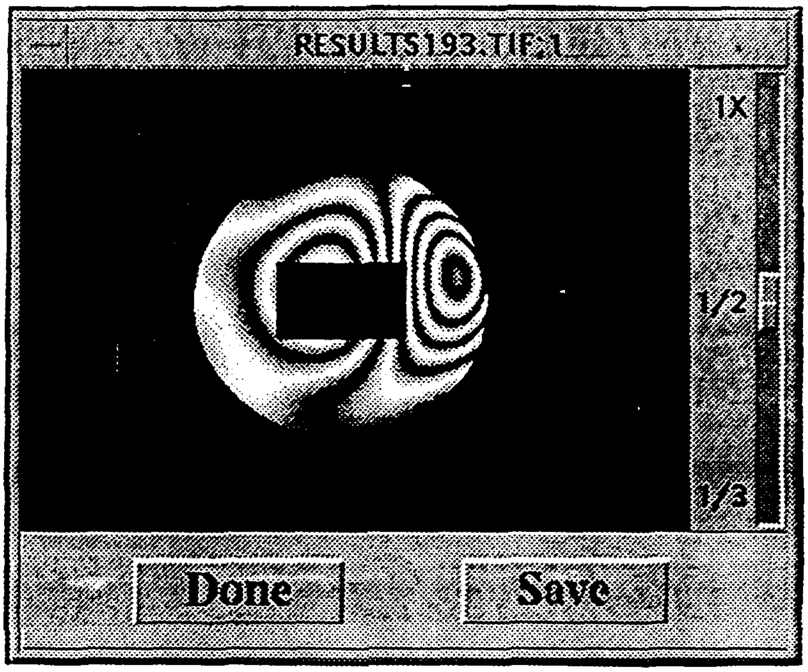
CODE USES

- Training code operators
- Limited inspection design


Surface Normal Motion
Non-Rigid Body Motion



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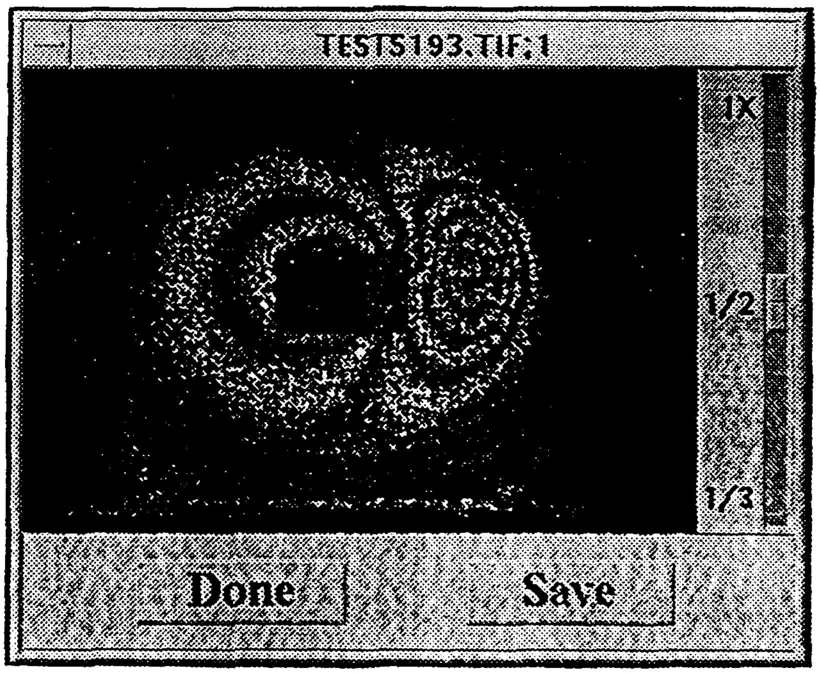
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1994
COHERENT OPTICS PROGRAM

1. Code Enhancement
2. Solid Modeling
3. Testing

New Mexico State University

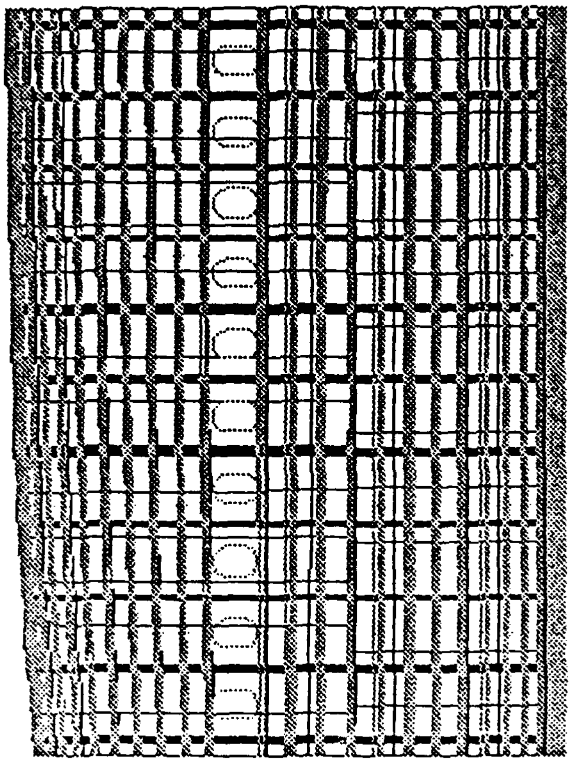
CODE ENHANCEMENT

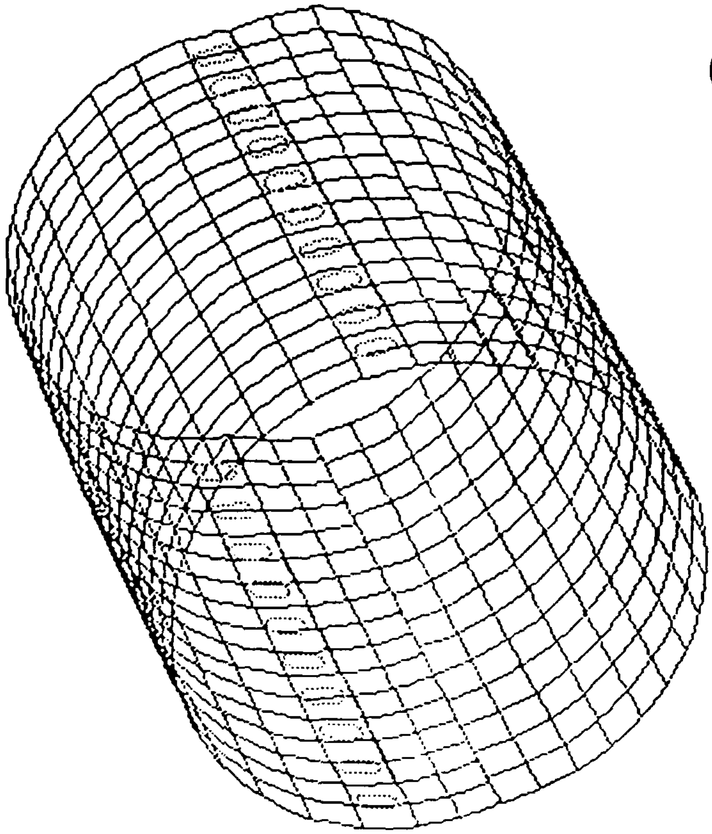
- Develop protocol for computer aided design (CAD) data input.
- Develop protocol for finite element (FEM) input.
- Graphical display of inspection configuration.
- Write user's manual for code; technical and training.
- Install Beta versions of the code.

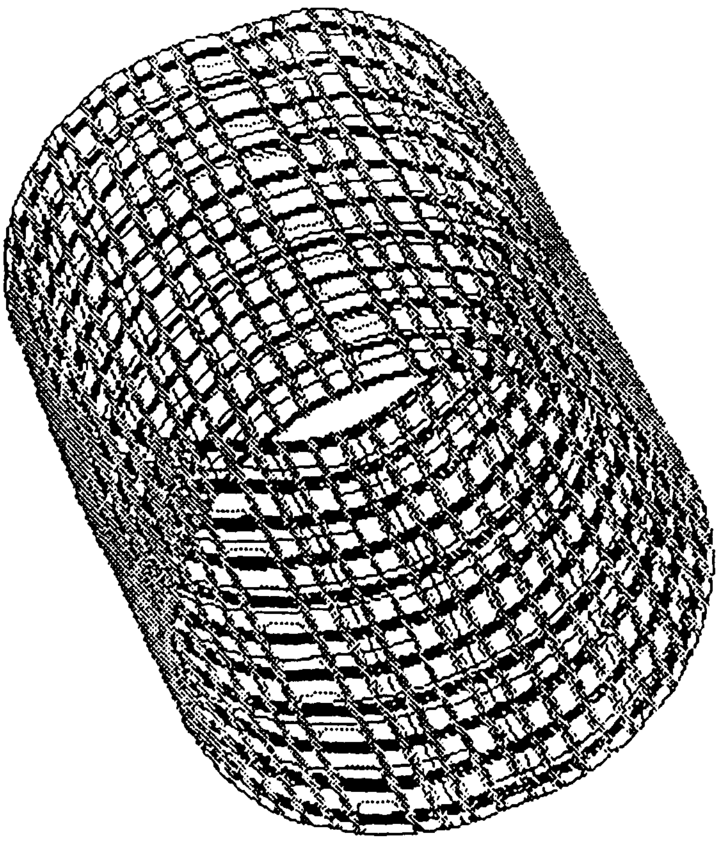
SOLID MODELING

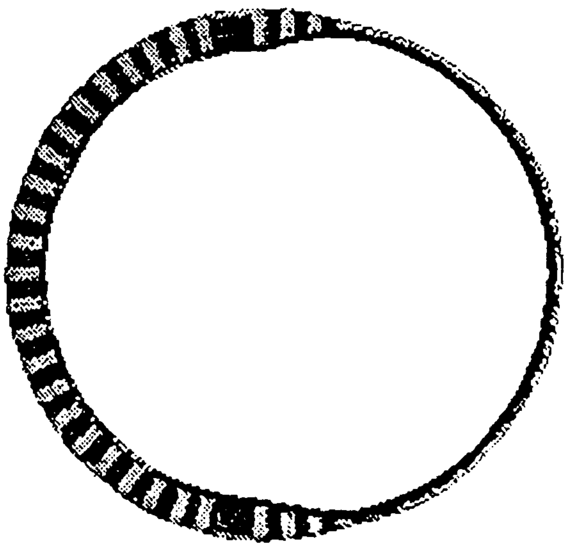
- Apply CAD and FEM data input capabilities to a few realistic aircraft geometries.
- Break structure into constitutive elements:
  -skin-stringers-frames-
  and determine influence of each on optical inspection.

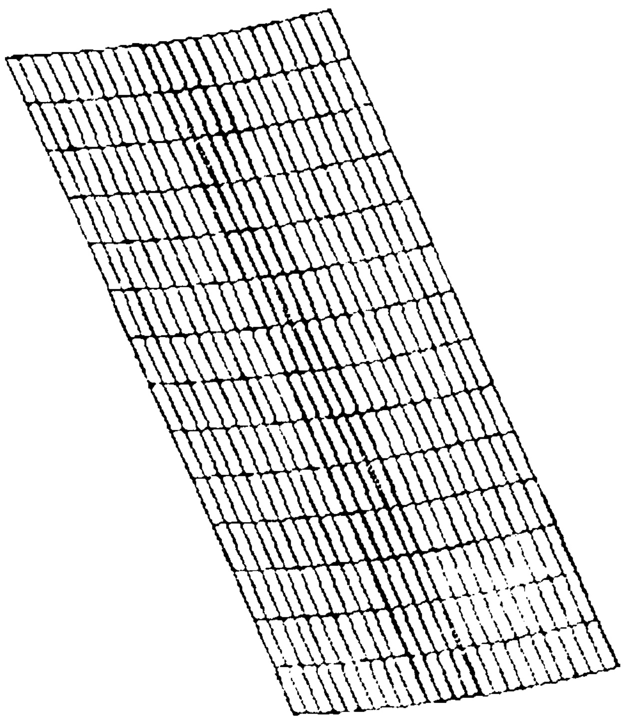
New Mexico State University

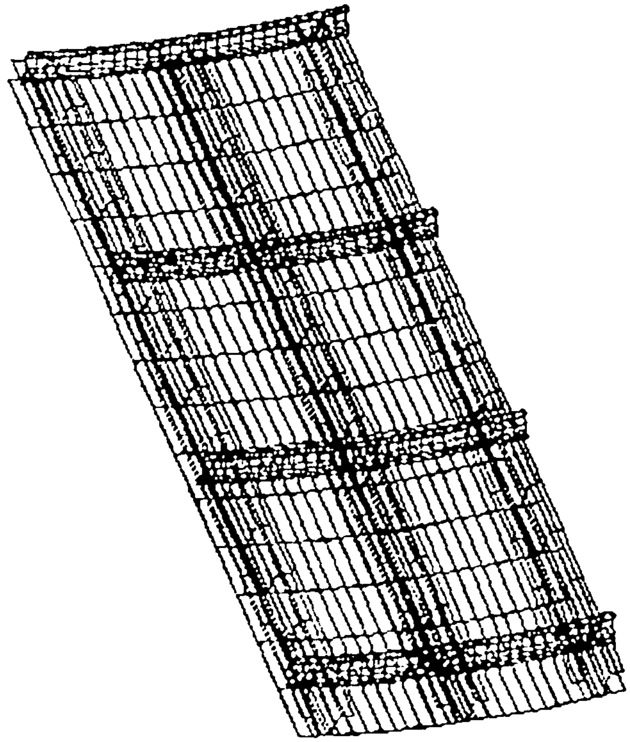


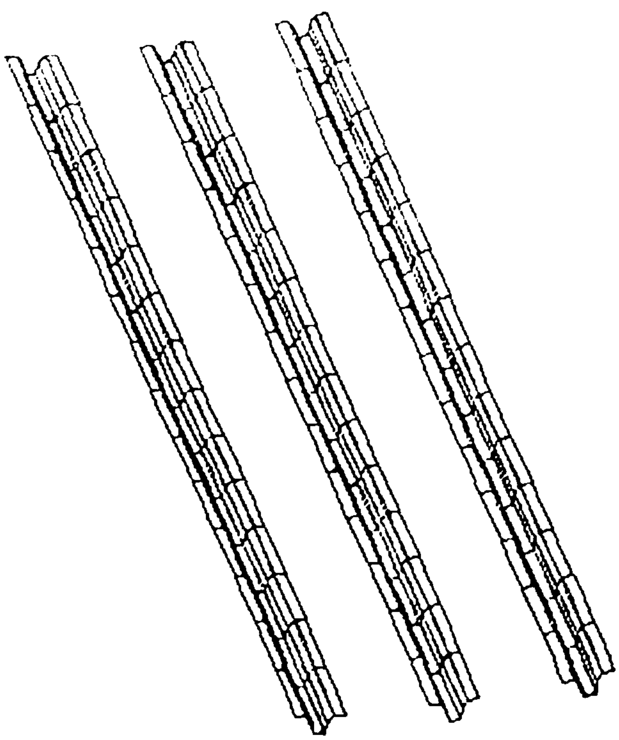


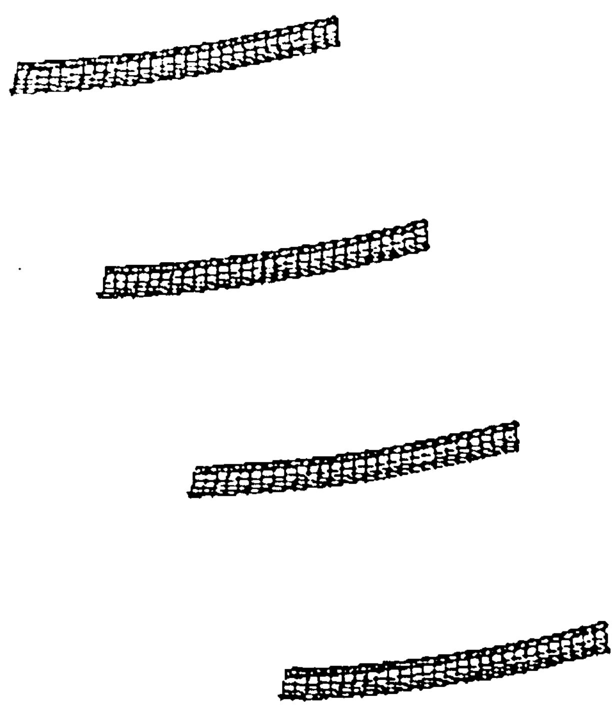


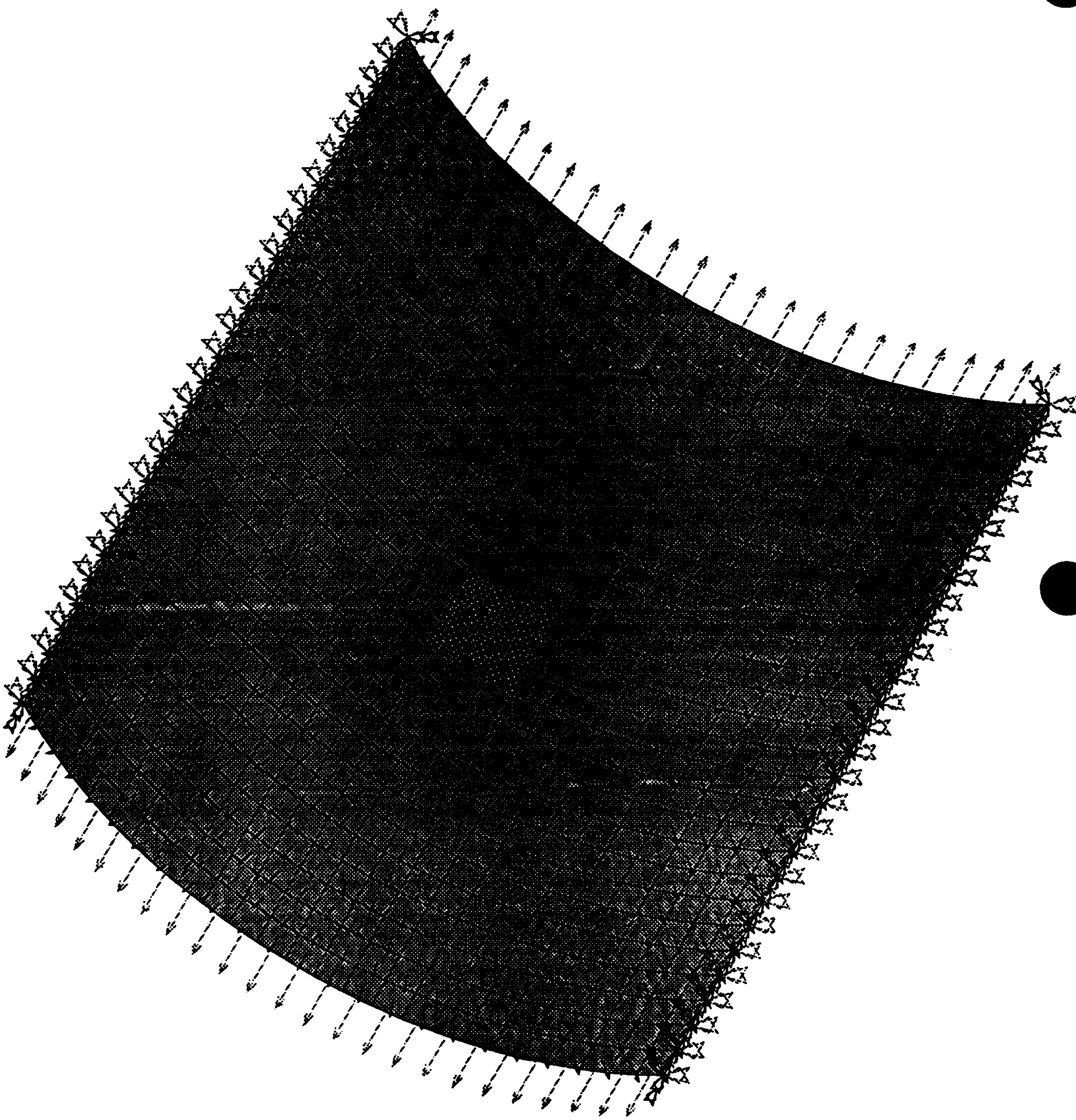












TESTING

The testing program is to support a series of tests to be conducted with AANC personnel at Sandia National Laboratories. The specific tasks we shall perform are:

- Optimize ESPI and Shearography setups.
- Predict fringe patterns.
- Quantitatively measure strain and deformation fields.

1994 DELIVERABLES

- Code for Beta testing
- Demonstration of quantitative measurement capabilities
- Report on influence of structural elements on flaw detection and repair design
- Accuracy requirements for geometric input

Schedule of Completion Dates

Image Compression	February 28, 1994
Help Screen Capabilities	March 15, 1994
LTI Test Results	April 1, 1994
Plotting Capabilities	May 1, 1994
Experiment Design	June 1, 1994
Finite Element Capabilities	June 15, 1994
Experiment	August 31, 1994
Experiment Results	November 1, 1994
Structural Elements Analysis	November 15, 1994
Computer Aided Design Capabilities	November 31, 1994
Graphical Interface	December 15, 1994
Geometric Requirements	December 15, 1994
User Manuals	December 31, 1994
Beta Tests	December 31, 1994

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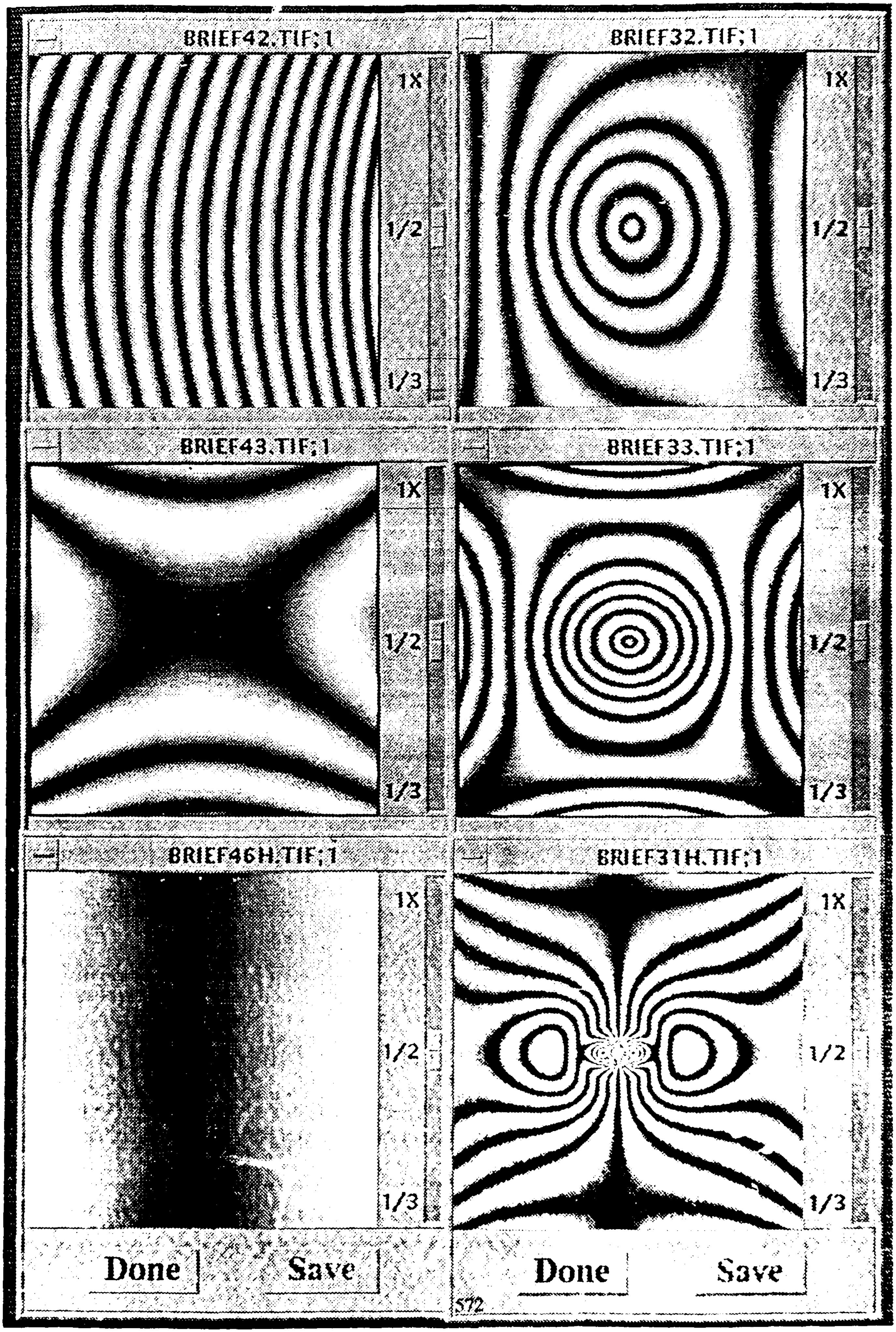
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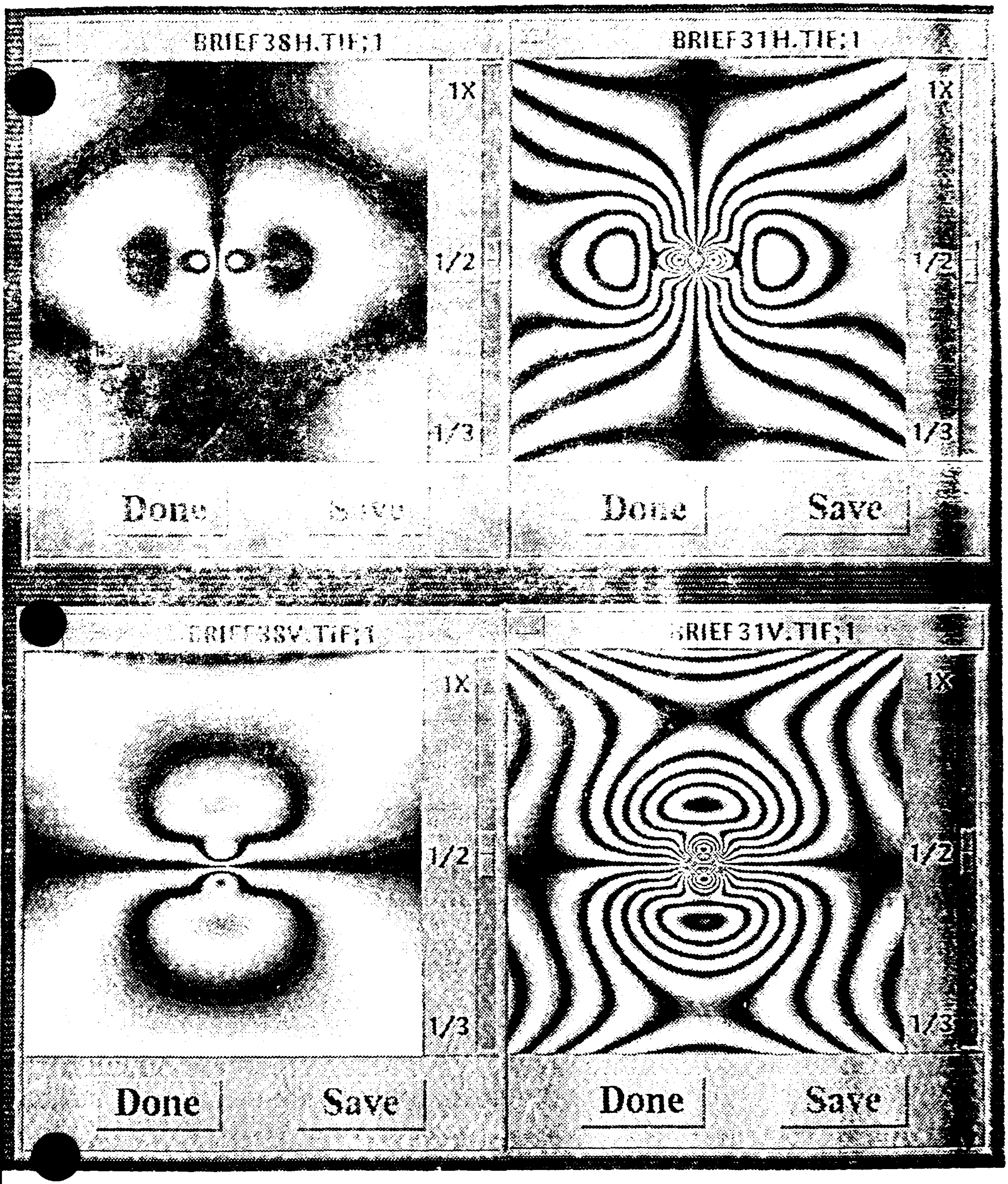
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Ultrasonic Guided Waves for Aging Aircraft

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Matthais K. T. Hansch

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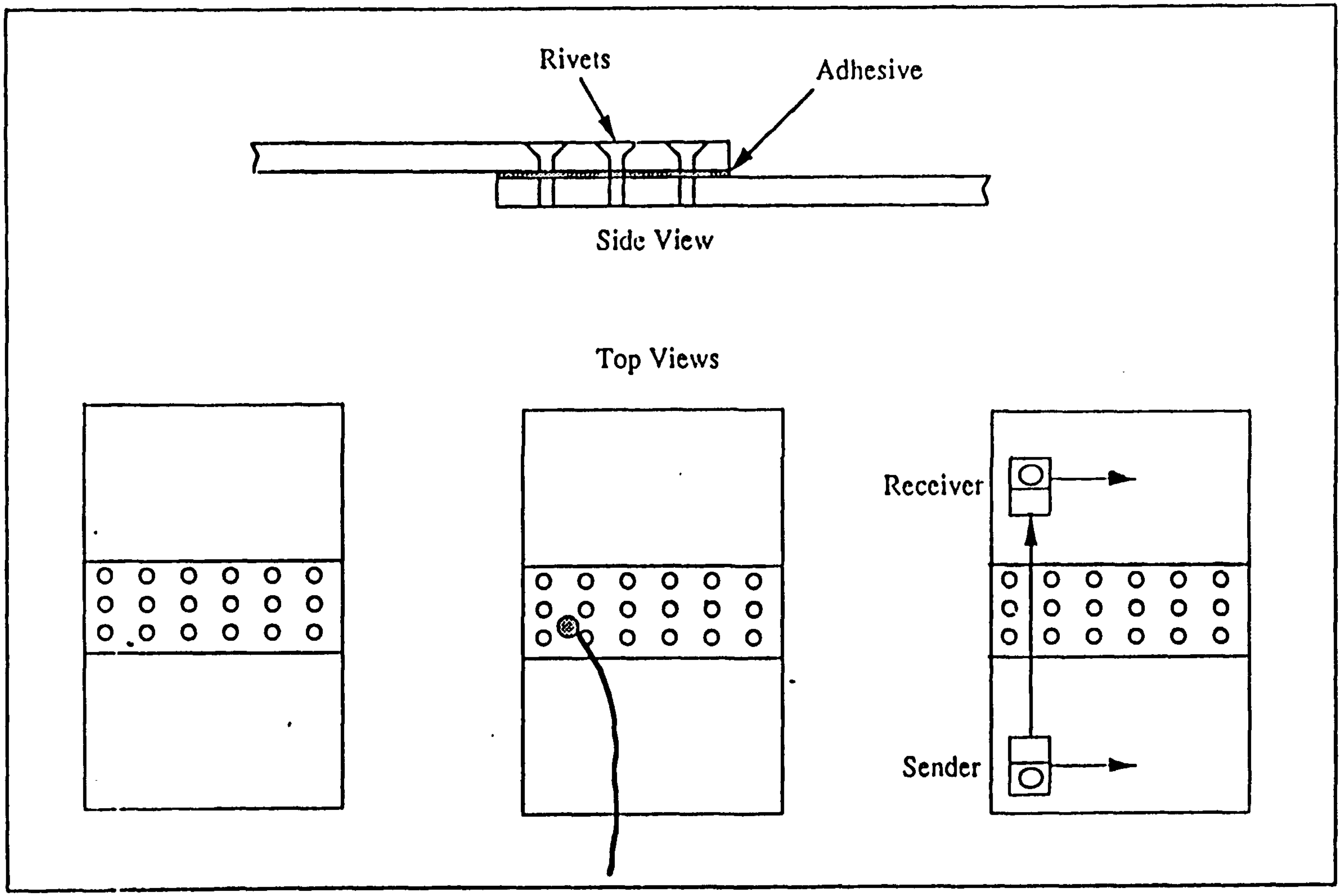
Department of Engineering Science and Mechanics
University Park PA 16801
Phone: (814) 863 8026
fax: (814) 863 8164

Contract Monitor: Dave Galella
Aging Aircraft Program
FAA Tech center
Atlantic City, NJ, 08405

Lamb Wave Versus Conventional Ultrasonic Inspection Technique



(A) Specimen

(B) Conventional Point by Point Technique

(C) Lamb Wave Technique

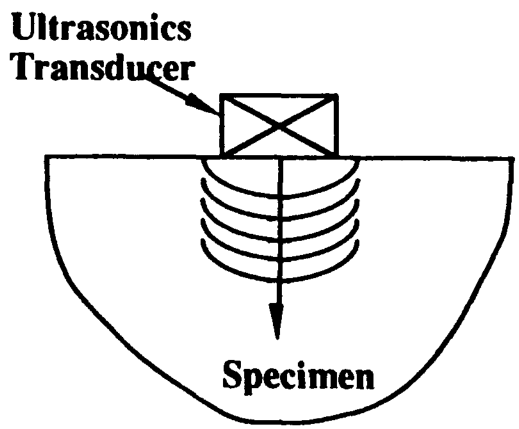
Goal

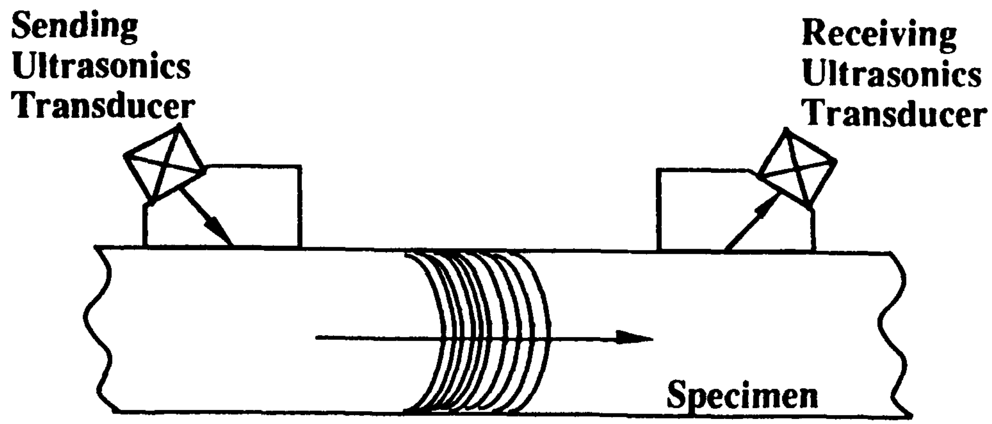
- To investigate the potential of ultrasonic guided waves for defect detection, location and classification in aging aircraft skin structures.

- To develop test procedures and to design a field probe

- To develop guidelines for handling the following:
  - Asymmetric structures
  - Stringers / Tear straps
  - Paint layers and sealants
  - Curvatures

Physical difference between *Bulk* and *Guided* waves





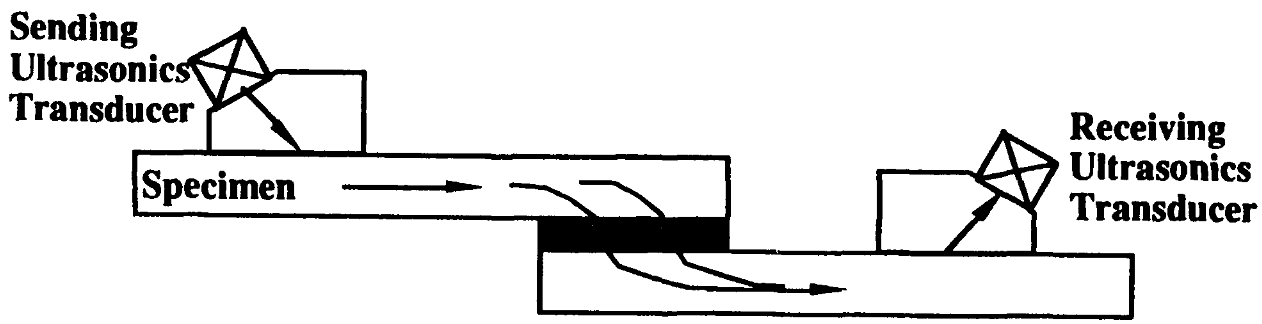
Bulk Waves

- Travel in the bulk of the material
- No boundary conditions to be satisfied
- Only longitudinal and shear modes

Guided Waves

- Depend entirely on the boundary
- Must satisfy boundary conditions
- Infinite number of modes

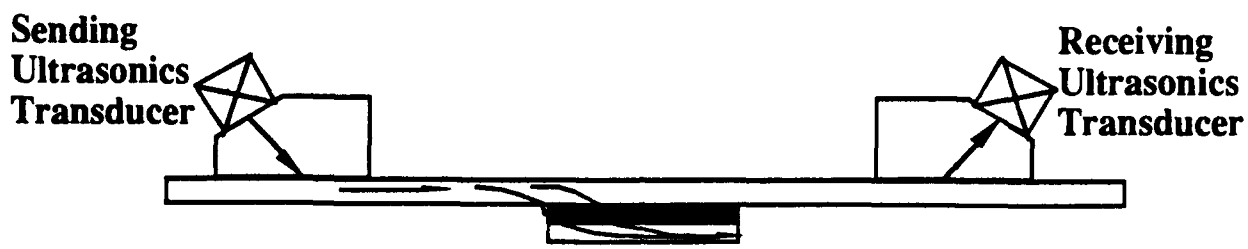
Basic Principle



Pitch - Catch: **Stringers**

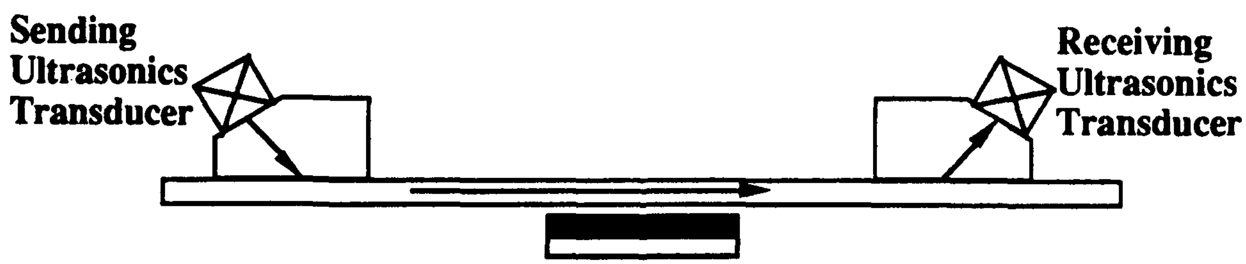
Good bond enables efficient energy from the upper to lower plate, thus a larger amplitude signal is detected by the receiver. Poor bonds give lower received amplitudes.

Tear Straps



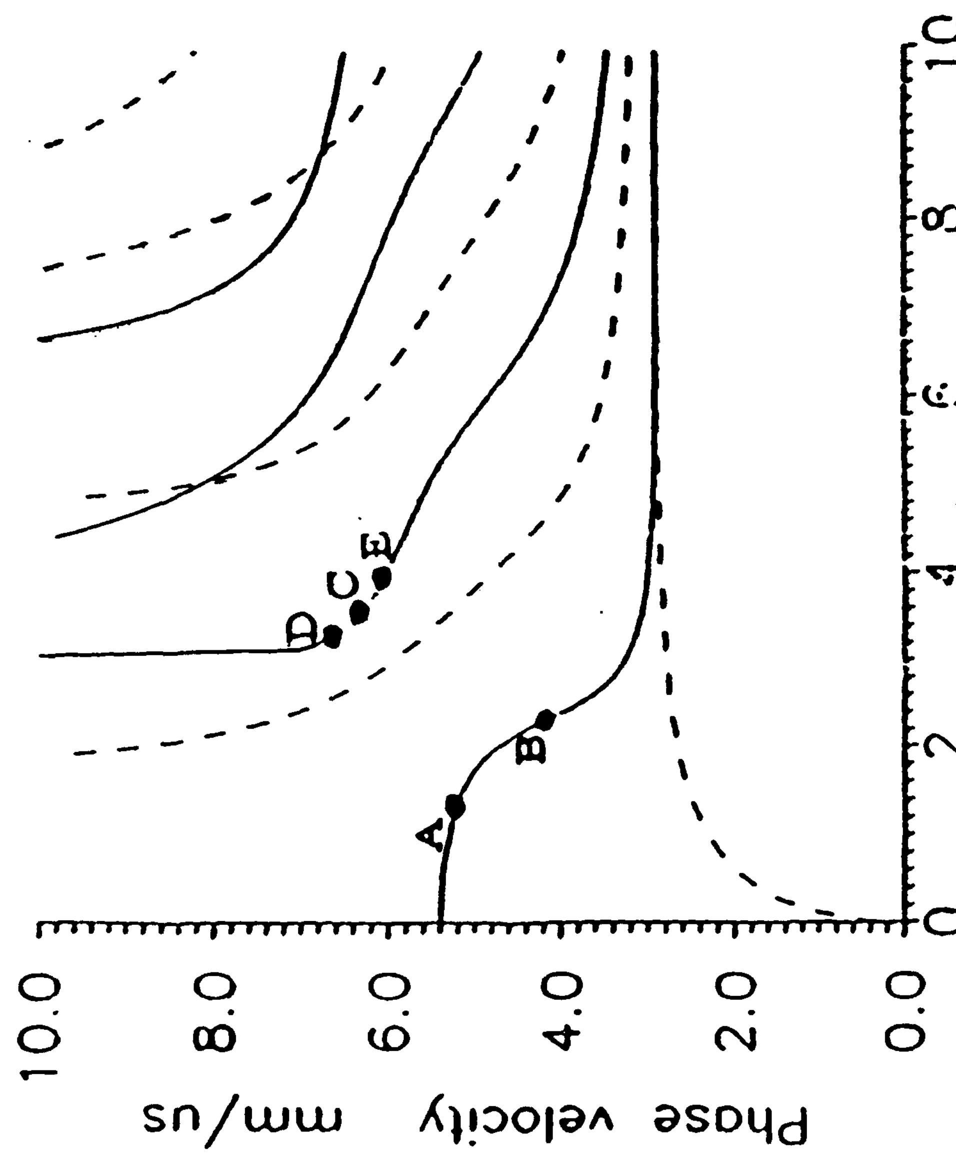
Good Bond - Leakage of Energy into tearstrap

Low received amplitude



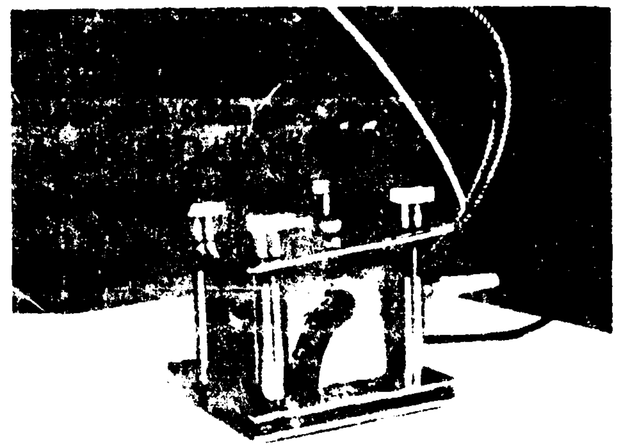
Poor bond- No leakage into tearstrap

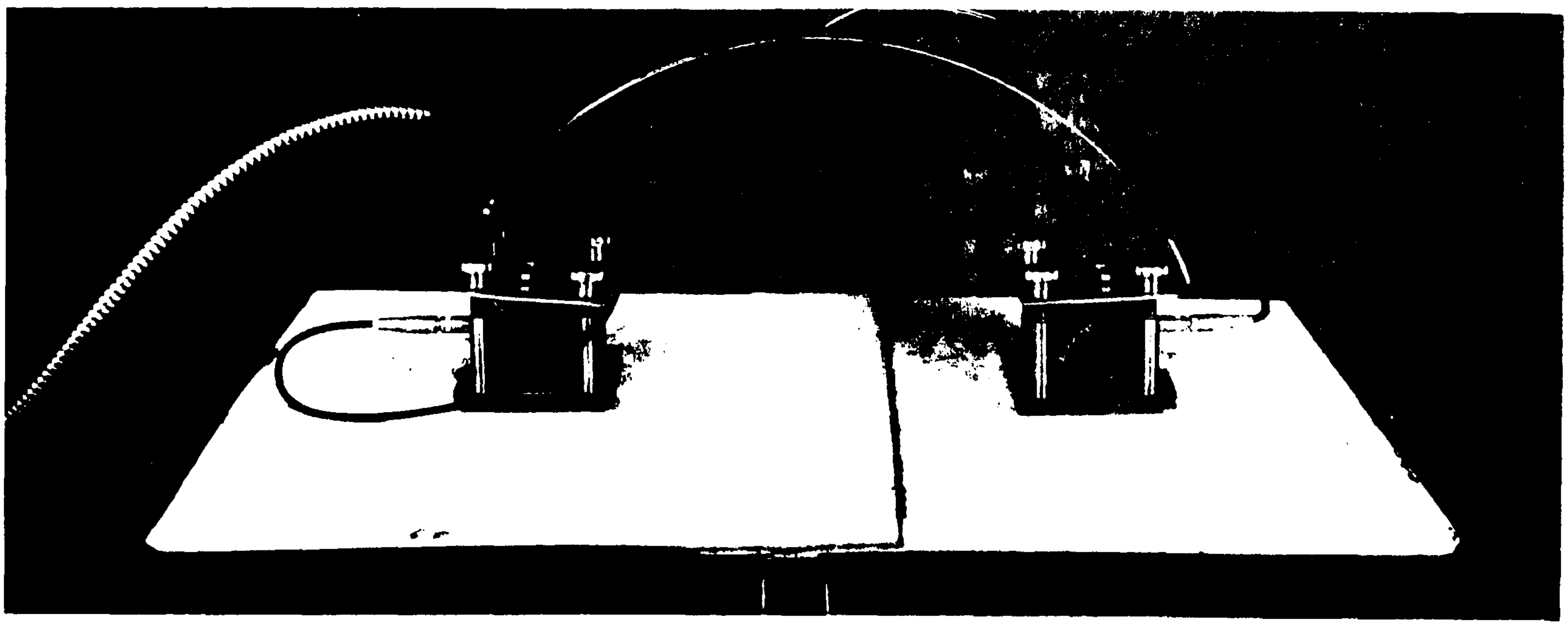
High received amplitude


Phase velocity mm/us
10.0
8.0
6.0
4.0
2.0
0.0
0
2
4
6
8
10
A
B
C
D
E

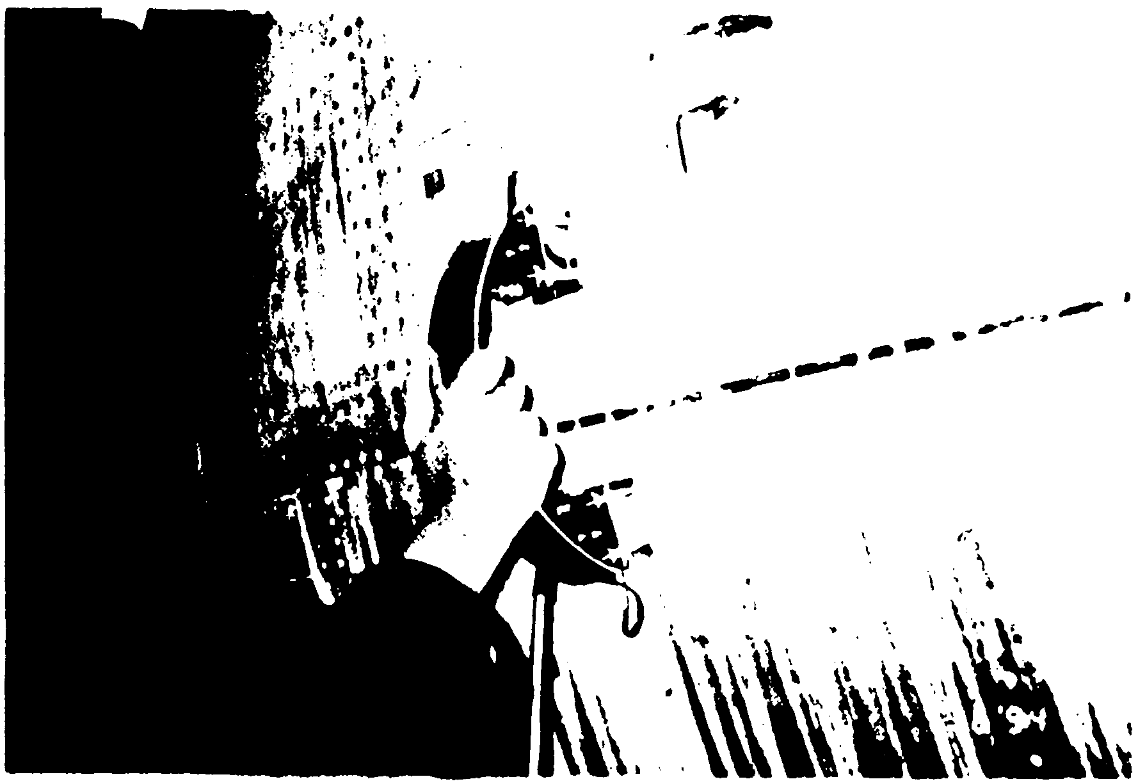
PENNSTATE

1855





Portable Hand Held Double Spring Guided Wave Probe For Aircraft Skin Inspection



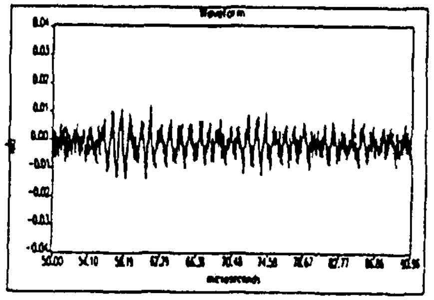
DOUBLE SPRING HOPPING PROBE

- Interchangeable transducers to select phase velocity
- Can use variable angle beam transducers
- Piezocomposite broad band elements
- Excellent surface contact
- Handle curvatures
- 2 step contact process via double spring
- Can test splice joints, tear straps, patch repairs, and skin corrosion

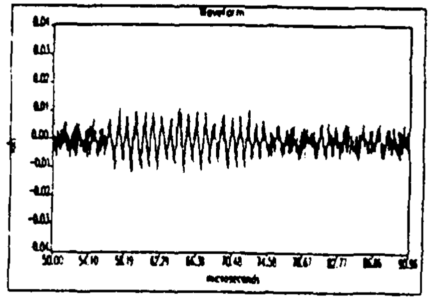
INSTRUMENTATION AND TEST PROTOCOL

- Can handle paint, coatings
- Can handle multilayer structures
- Variable frequency and bandwidths via swept frequency toneburst
- High voltage excitation levels possible
- Pulse echo or thru-transmission
- Can tune to structure for optimal inspection potential

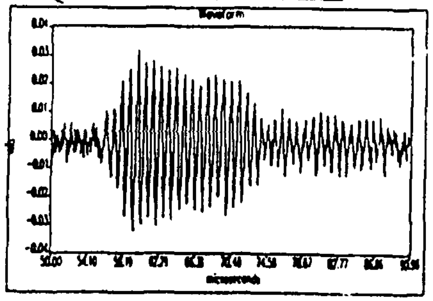
SPLICE LAP JOINT INSPECTION WITH FREQUENCY TUNING



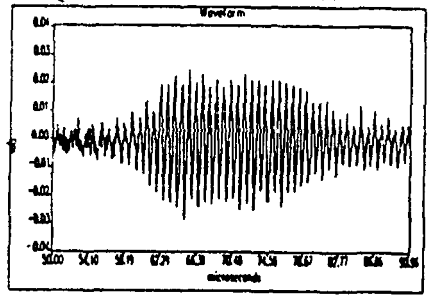
FRQ088 0.875 MHz



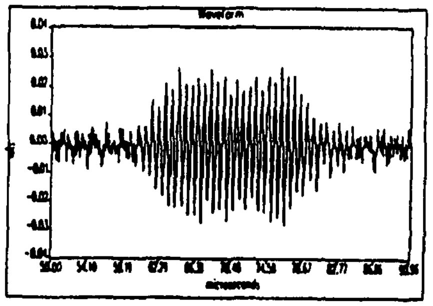
FRQ100 1.000 MHz



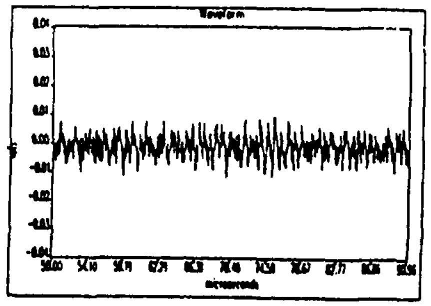
FRQ113 1.125 MHz



FRQ125 1.250 MHz



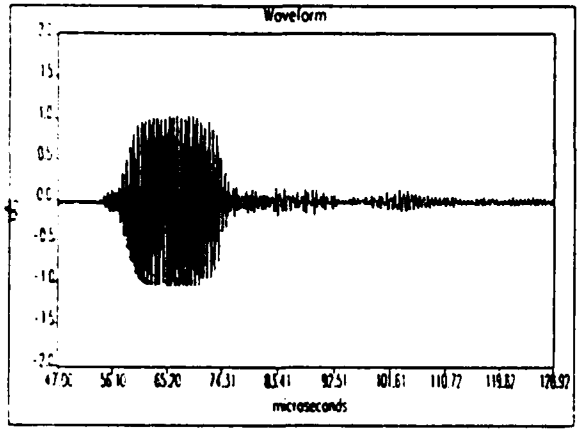
FRQ138 1.375 MHz



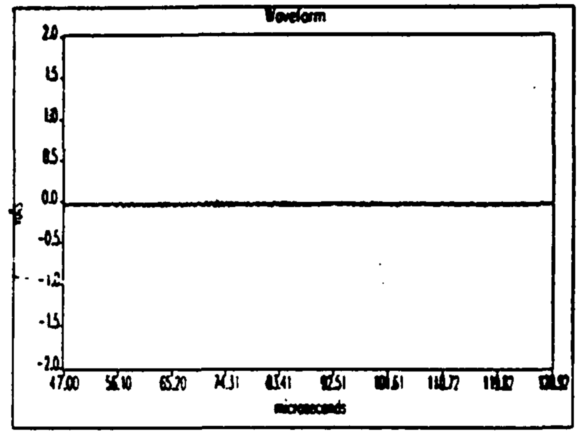
FRQ150 1.500 MHz

Results from Boeing 737-222

(Tests conducted at Sandia National Laboratories, Albuquerque, NM.)

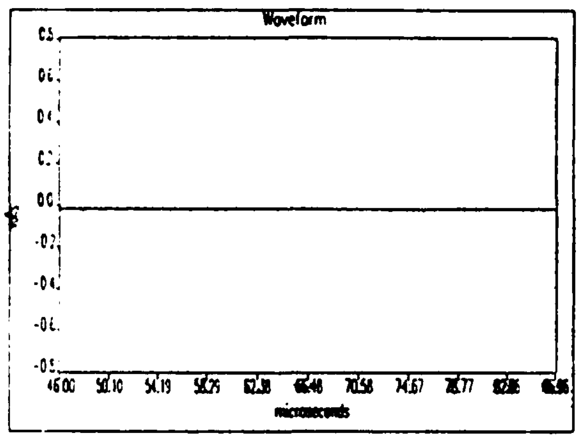


a. Good bond

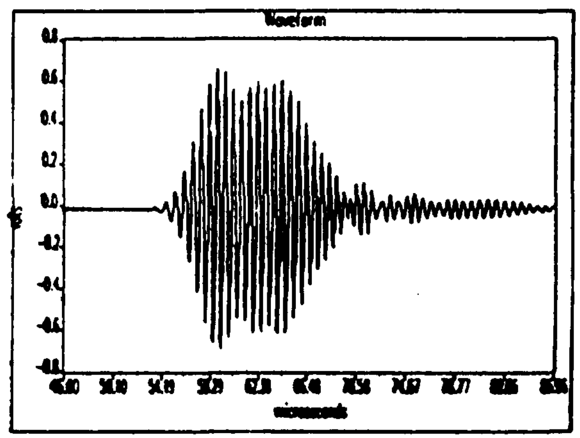


b. Poor bond

Sample RF-waveforms from a lap splice joint.



a. Good bond



b. Poor bond

Sample RF-waveforms from a bonded tear strap.

Most Recent Accomplishments

- A Double Spring Hopping Probe (DSHP) is developed, tested on lab standards and also on Boeing 737-222.
- DSHP demonstrated ability to handle a variety of joint configuration with stringers, tear straps, etc.
- Concepts of inspection of lap splice joint configuration via frequency tuning are being studied.
- Theoretical studies are in progress to address influence of acoustic damper pads.
- Influence of layers of paint and zinc chromate are being studied.
- Preparation are underway to test the Boeing 737-222 in early August, 1994 with modified DSHP for improved human interaction.

Future Directions

- Modify probe design to improve performance, sensitivity to defects, coupling and ease of operation.
- Develop standard defect specimens and calibration procedures.
- Perform probability of detection studies for various defect types and sizes.
- Perform an aircraft coverage analysis to see where the Lamb wave technique is applicable.
- Develop software for "in the field" data acquisition and analysis.
- Integrate the Lamb wave probe and equipment into a compact, field portable and operator friendly system.
- Initiate studies on more defect types (corrosion, weak interfaces, cracking) in specimens and real samples.

Future Directions (Cont'd)

- Study more geometric and thickness situations including tear straps, stringers, etc...
- Initiate more physical modeling of geometry and defect types.
- Develop mode selection criteria for different geometric structures and defect types.
- Develop a protocol to handle rivets.
- Consider different couplant possibilities to increase repeatability of technique. (Dry contact, bubbler, hopping, etc...).
- Develop routines to handle/compensate for curvature and paint influences.
- Evaluate benefits of multimode vs. single mode generation for defect detection, classification, sizing, etc...

NDI for Corrosion Detection
RPI 205

FAA Center for Aviation Systems Reliability

Project:	**NDI Reliability**
Task:	**Eddy Current Methods for Corrosion Detection**
Principal Investigator:	**J. Moulder**
FAA Sponsor:	**R. Yarges**
FAA Technical Monitor:	**D. Galella**
Industrial Contacts:	**Boeing, McDonnell Douglas, Northwest Airlines**

FAAREV ISU 4-94

NDI for Corrosion Detection
RPI 205

FAA Center for Aviation Systems Reliability

Task: **Eddy Current Methods for Corrosion Detection**

Objective: **To seek quantitative eddy current methods for determining corrosion-induced metal loss in multi-layer lap joints.**

Deliverables:

3/93 Interim report specifying swept frequency measurement method for measuring corrosion-induced metal loss in first and second layers of aircraft lap joints.

12/93 Interim report specifying methods for adapting swept frequency method to commercially available multi-frequency eddy current equipment.

6/94 Final report specifying a prototype pulsed eddy current instrument and data inversion method for characterizing corrosion-induced thinning in aircraft lap joints.

FAAREV ISU 4-94

NDI for Corrosion Detection
RPI 205

FAA Center for Aviation Systems Reliability

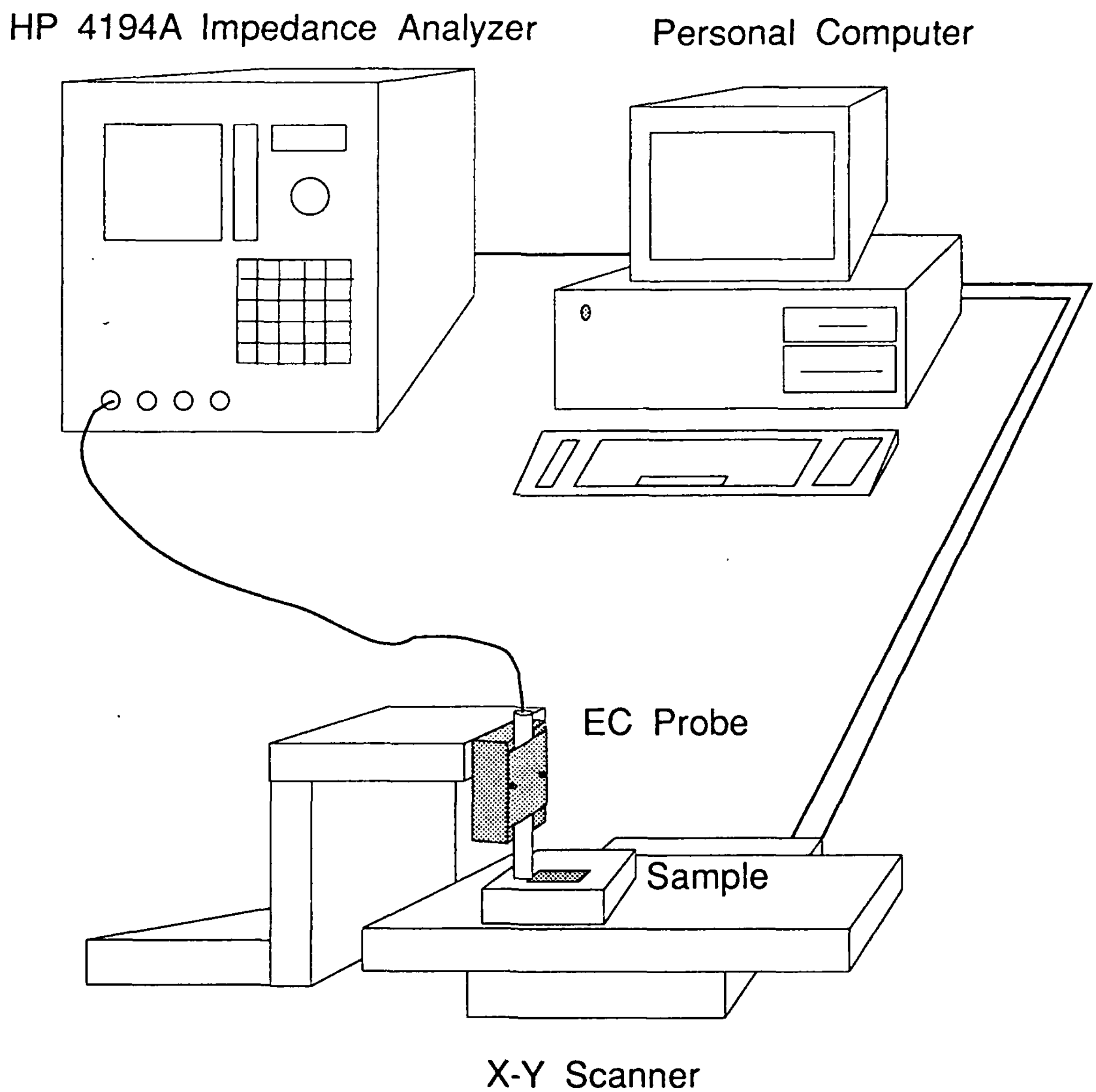
Task: **Eddy Current Methods for Corrosion Detection**

Accomplishments to date:

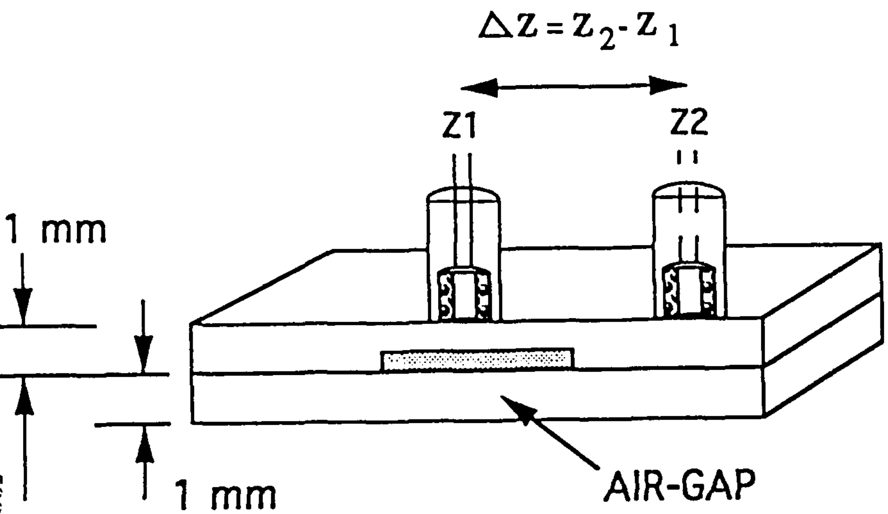
- Developed, validated inversion method for swept frequency technique
- Studied effect of size of corroded area on ec measurements
- Completed pulsed eddy current prototype instrument
- Developed calibration method for commercial ec instruments
- Made quantitative measurements with calibrated Zetec MIZ-40
- Demonstrated ability of pulsed ec to detect corrosion loss in both layers
- Identified method for discriminating between corrosion and air gap

FAA ISU 4-94

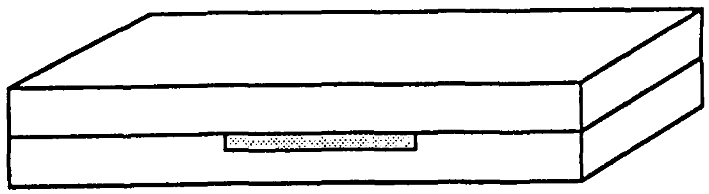
Automated Eddy-Current Workstation



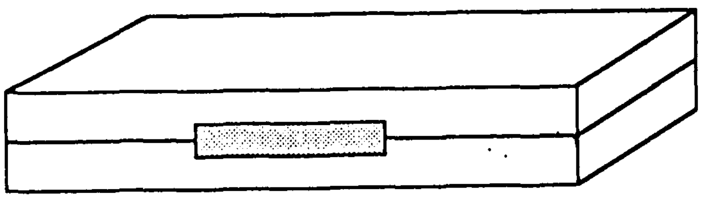
TOP PLATE THINNED



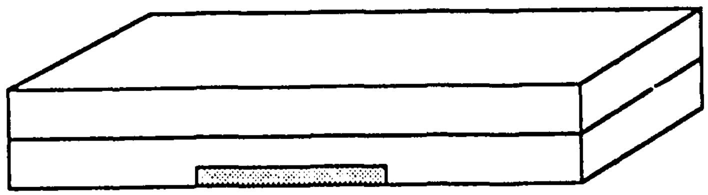
BOTTOM PLATE THINNED



BOTH PLATES THINNED

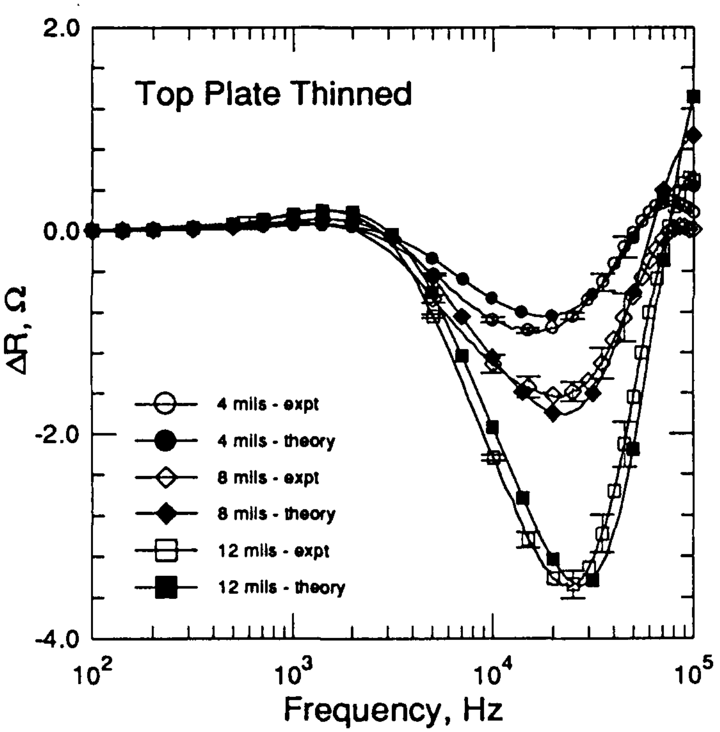


BOTTOM SURFACE THINNED

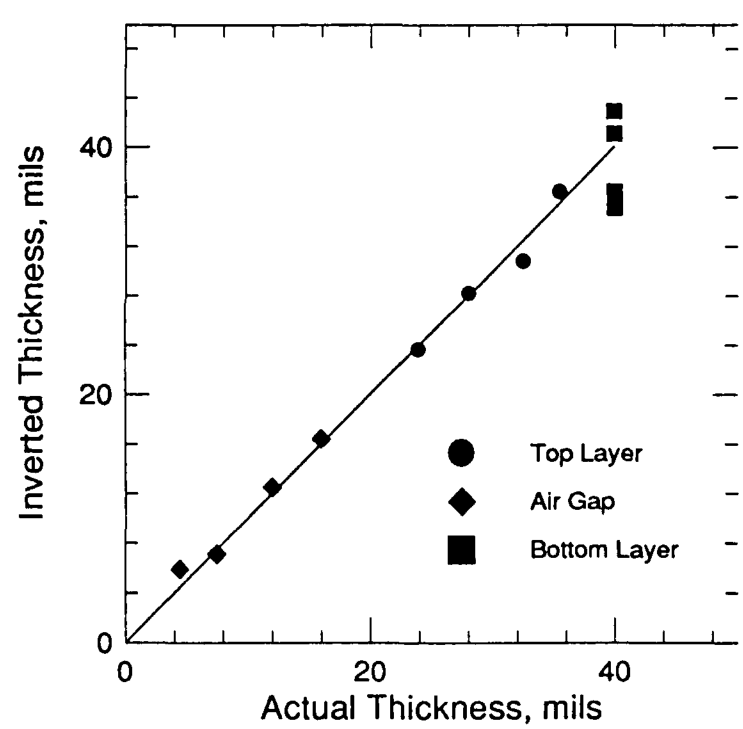


Eddy Current Methods for Corrosion Detection

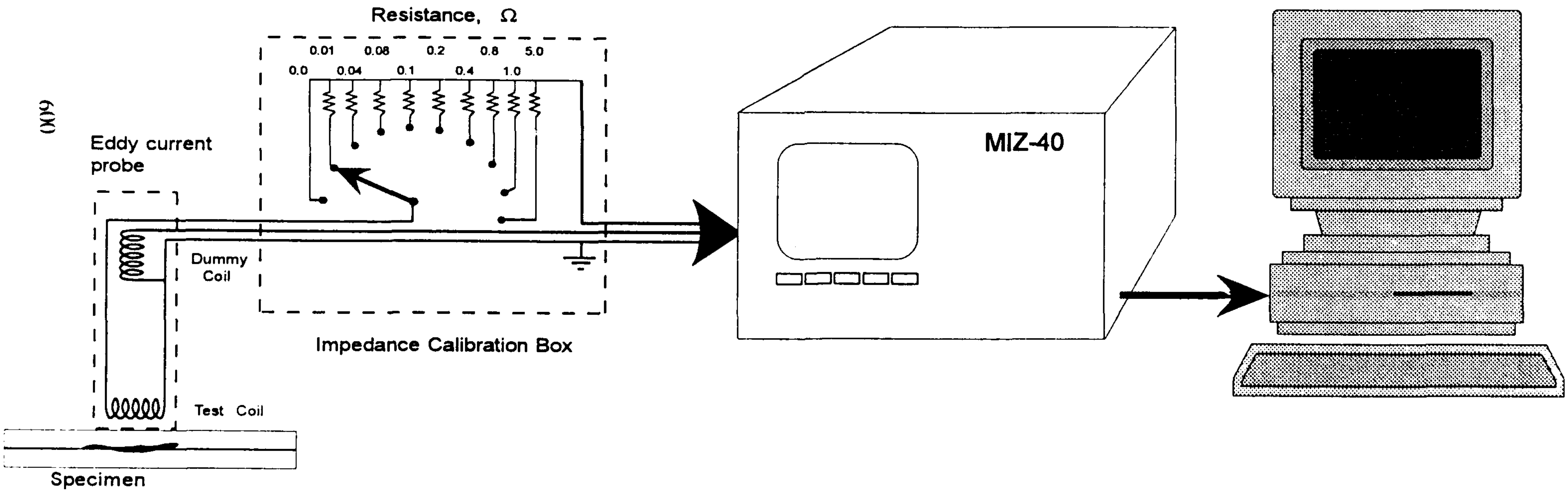
Swept-Frequency Measurements
Compared to Model Results



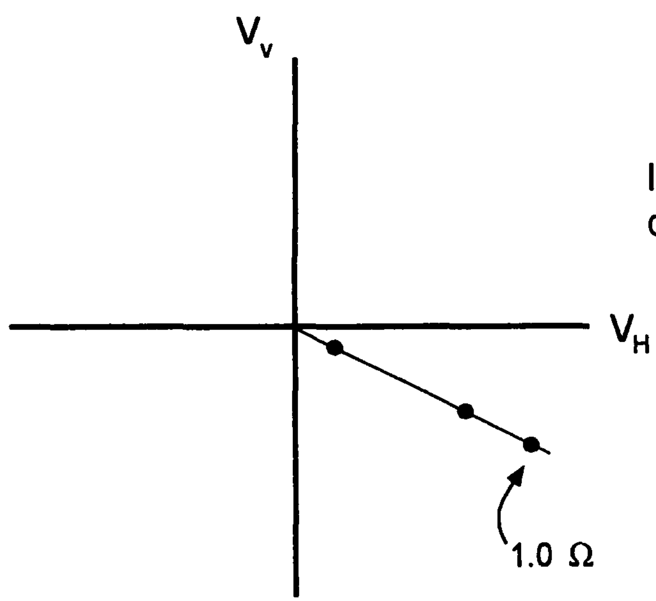
Thickness of Both Plates
Inferred from Measurements

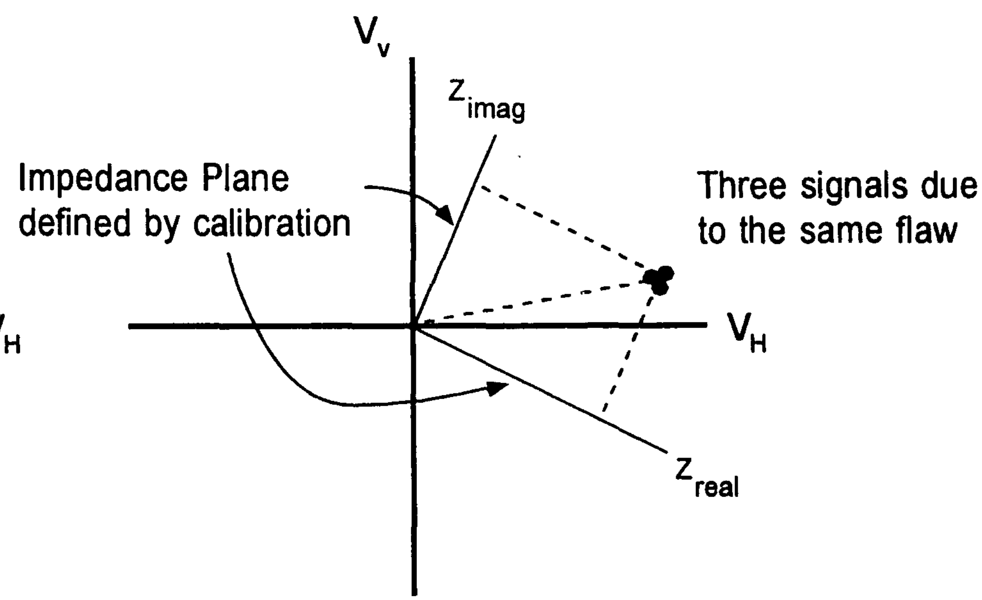


Experimental Set-up for Calibrated Eddy Current Measurements with Commercial Equipment



Quantitative Measurements Using Commercial Eddy Current Instruments





The voltage magnitude is directly proportional to the change in calibration resistance and its direction defines the Z_{real} axis.

Signal from flaw is projected onto the calibrated impedance plane (Real, Imag) to determine flaw impedance quantitatively

Variables That Affect Calibration

- <u>Eddy Current Instrument Gain Setting</u>

  - Calibration done at one gain setting (dB)
  - Measurements taken at other gain settings must be factored by the gain ratio before using calibration curves

- <u>Eddy Current Instrument Probe Drive Voltage</u>

  - One setting is chosen for a probe and maintained for all measurements taken with that probe

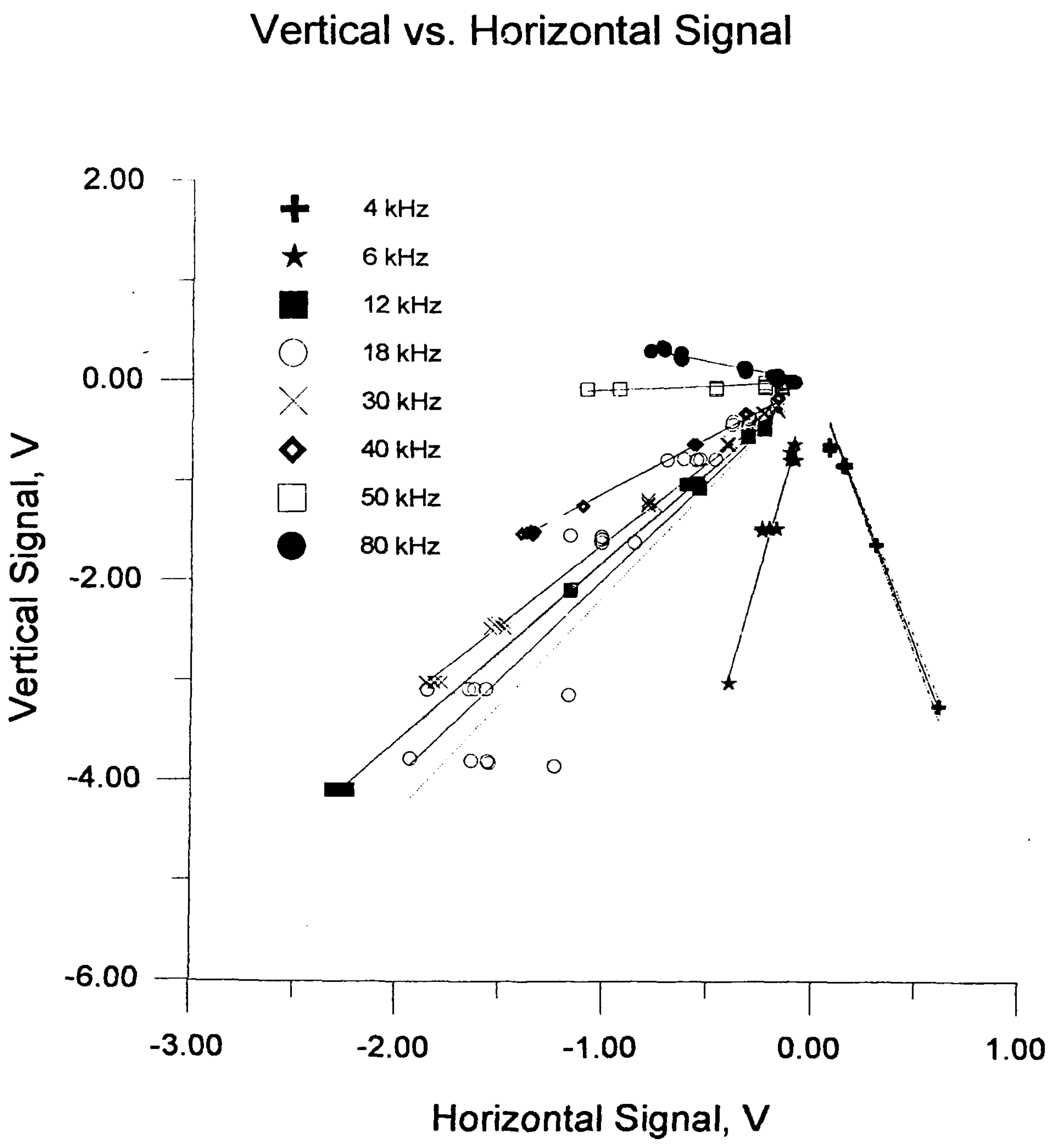
- <u>Probe Coil</u>

  - Each probe has one separate set of calibration curves
  - Due to differing impedance across bridge circuit

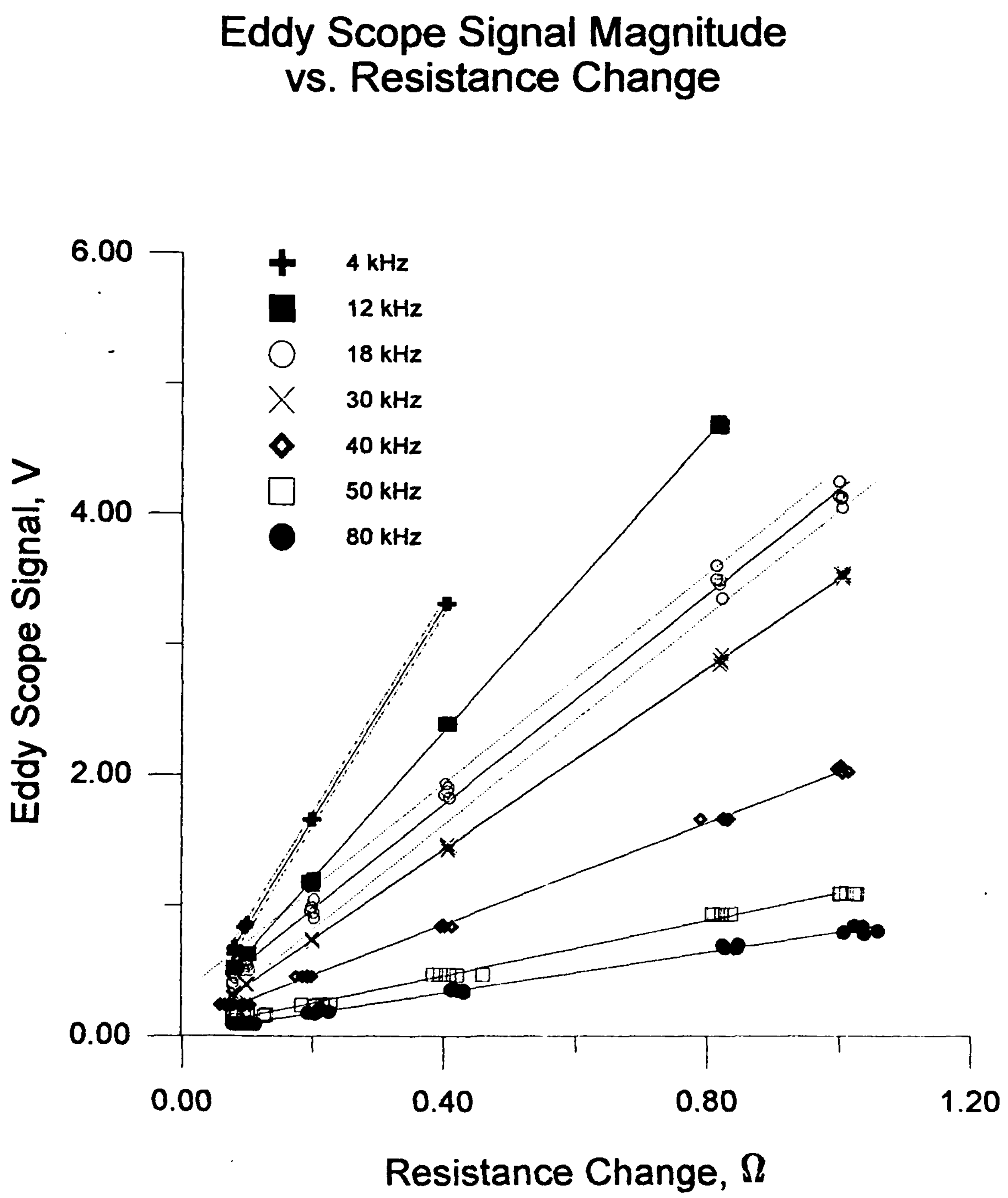
- <u>Probe on Metal or in Air</u>

  - All calibrations done with probes on the metal
  - Minimal effect on phase shift and magnitude when probe is in air

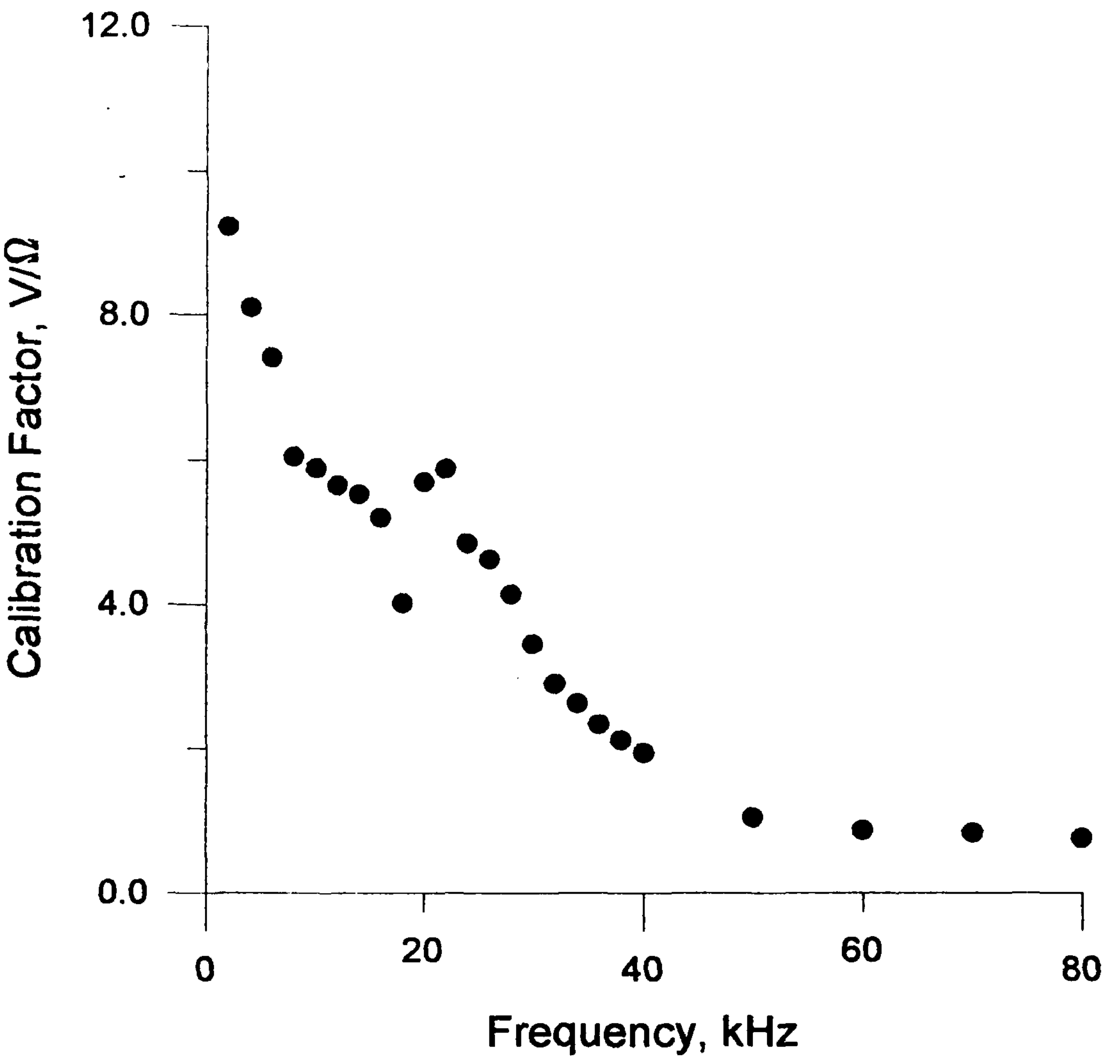
Zetec Eddy Current Instrument Calibration Curves



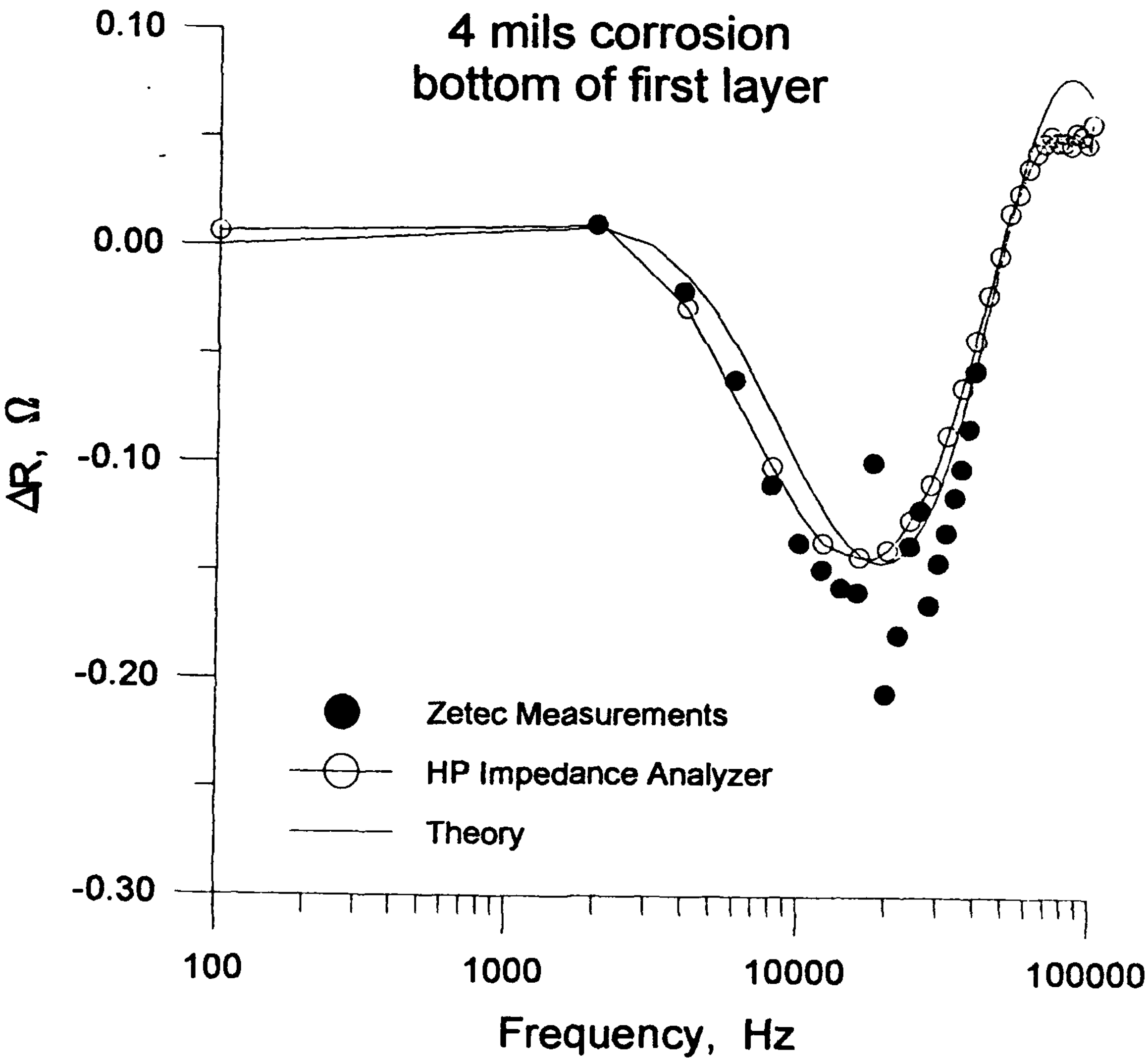
Zetec Eddy Current Instrument Calibration Curves



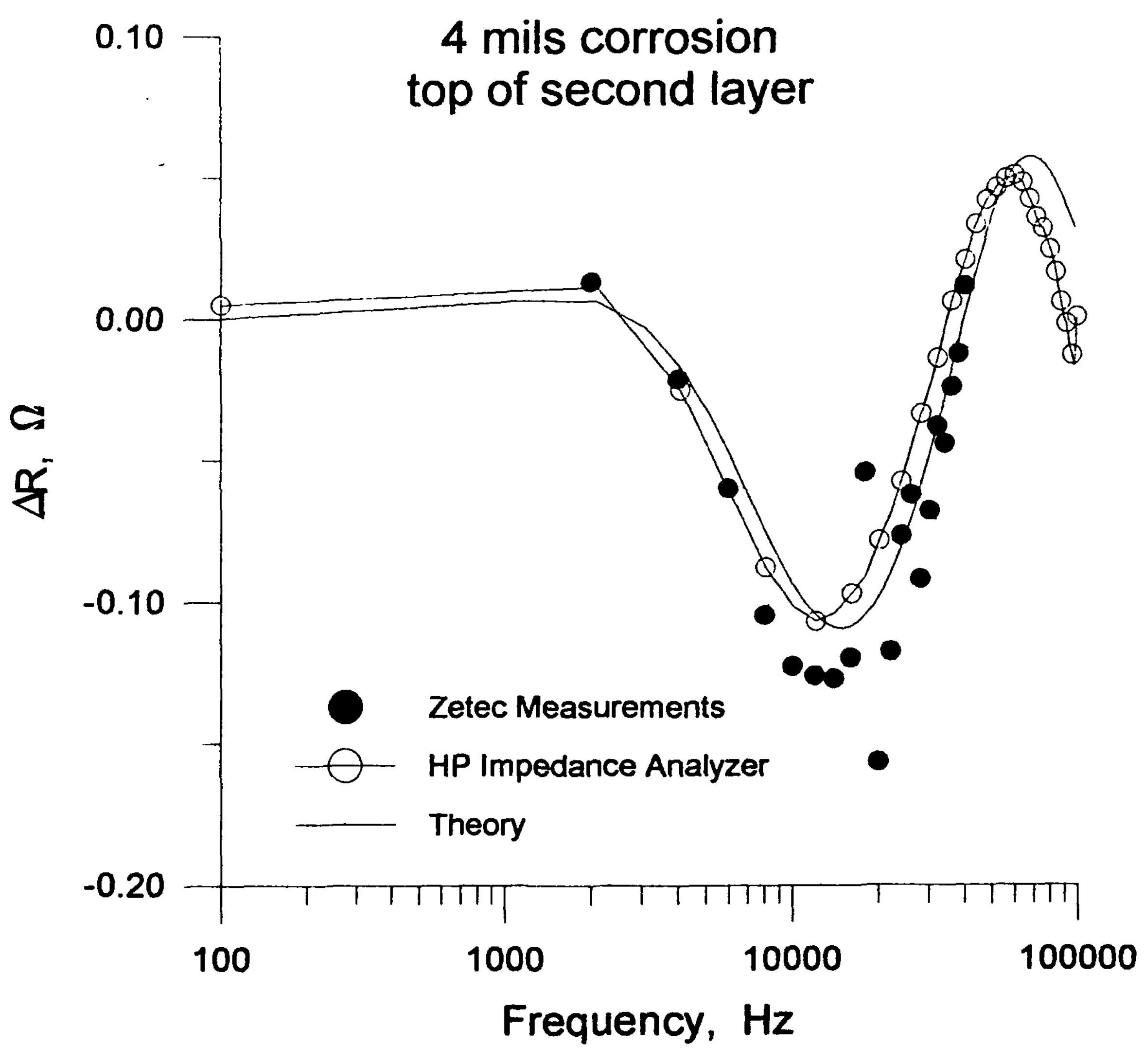
Calibration Factor vs. Frequency



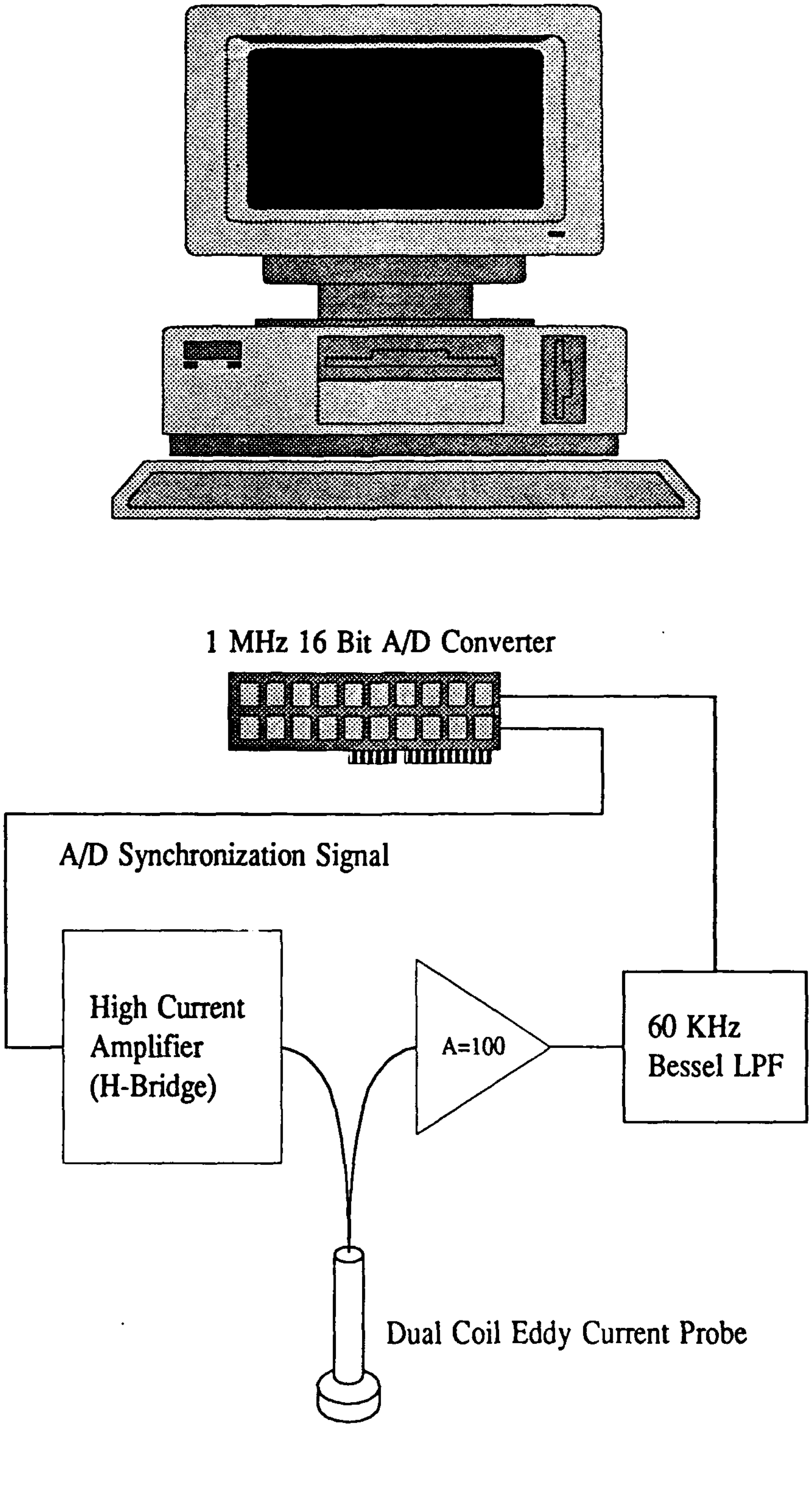
Zetec Eddy Current Instrument vs. HP Impedance Analyzer



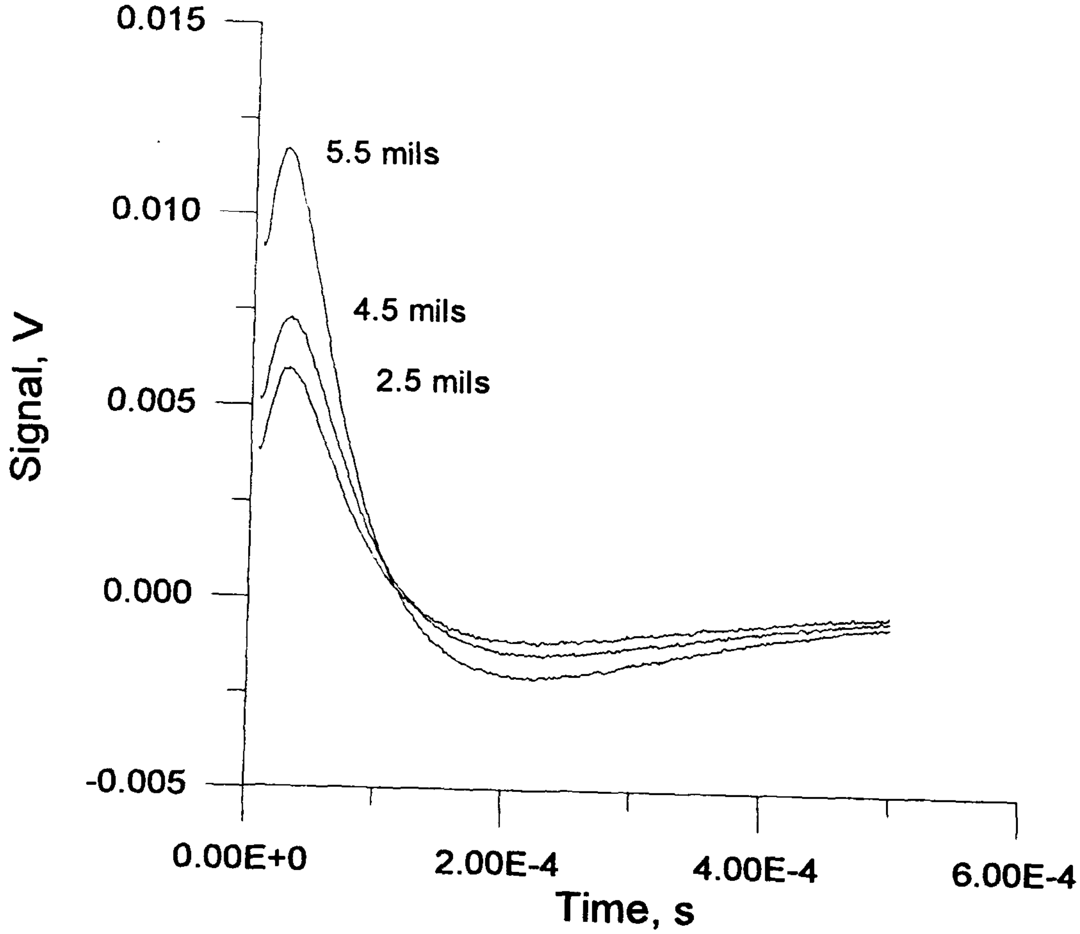
Zetec Eddy Current Instrument vs. HP Impedance Analyzer



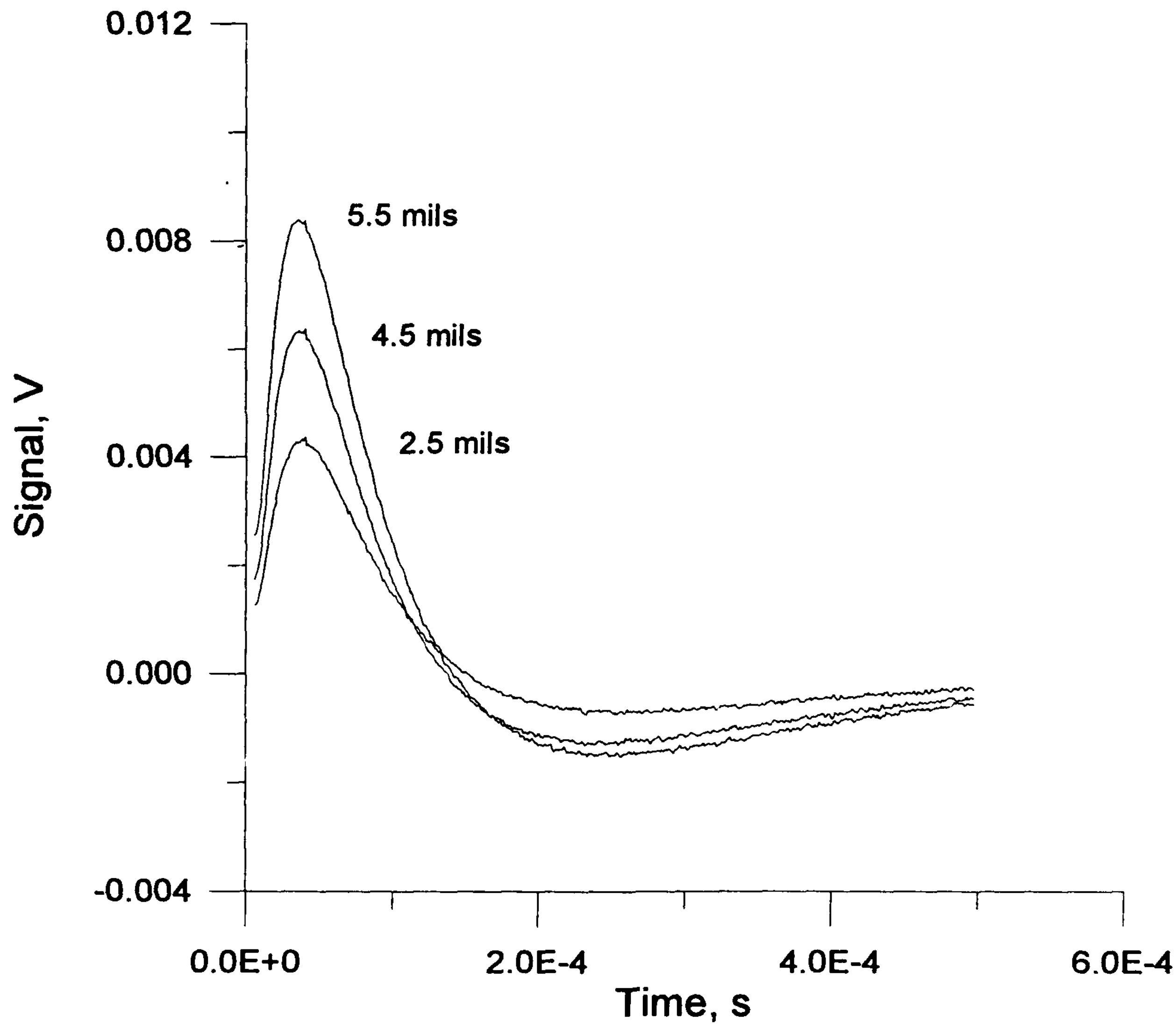
Block Diagram of 16-Bit High Speed Pulsed Eddy Current Apparatus



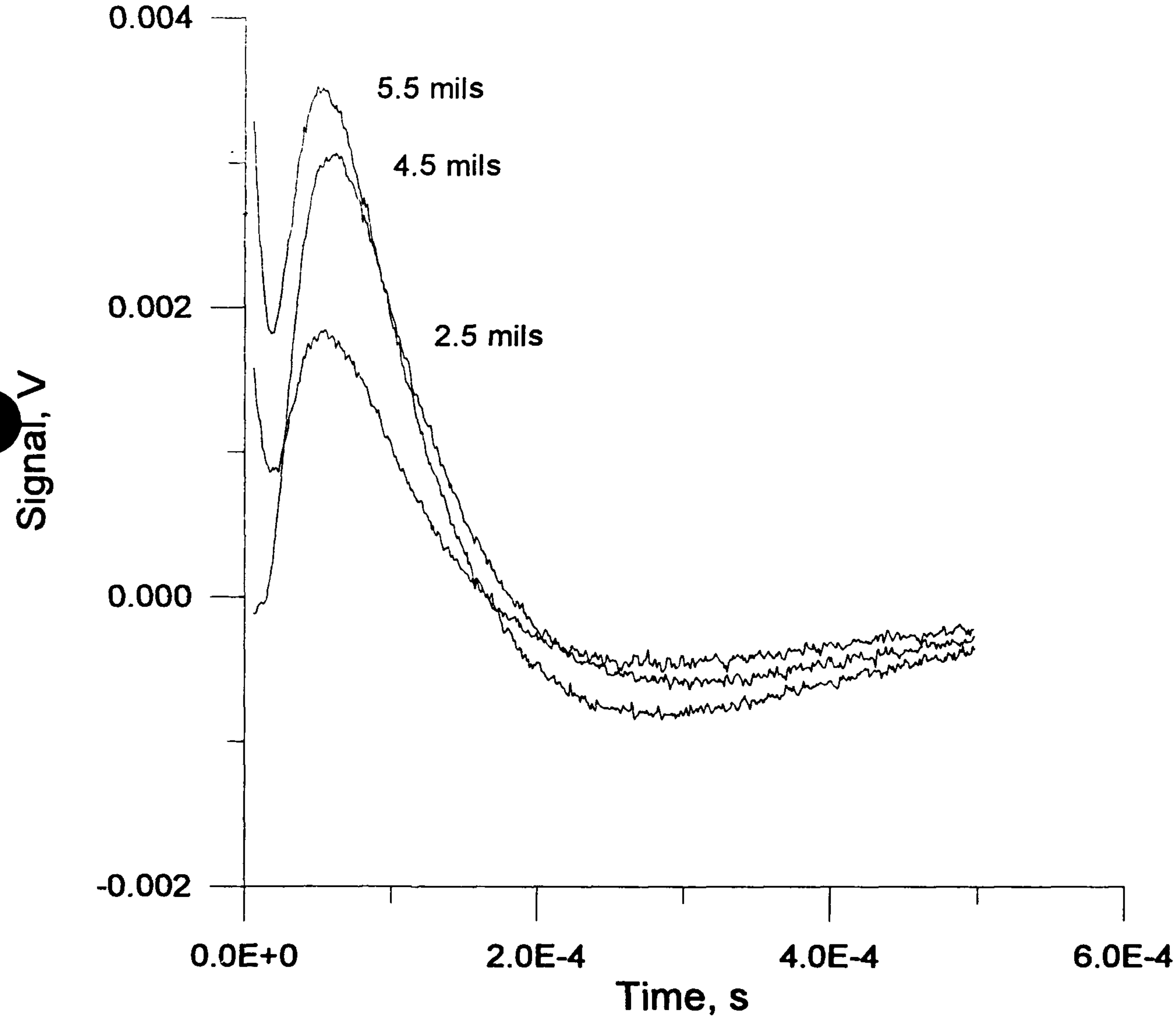
Simulated Corrosion in Top Layer



Simulated Corrosion Top of Second Layer



Simulated Corrosion on Bottom of Second Layer



Penetration Through Multiple Layers

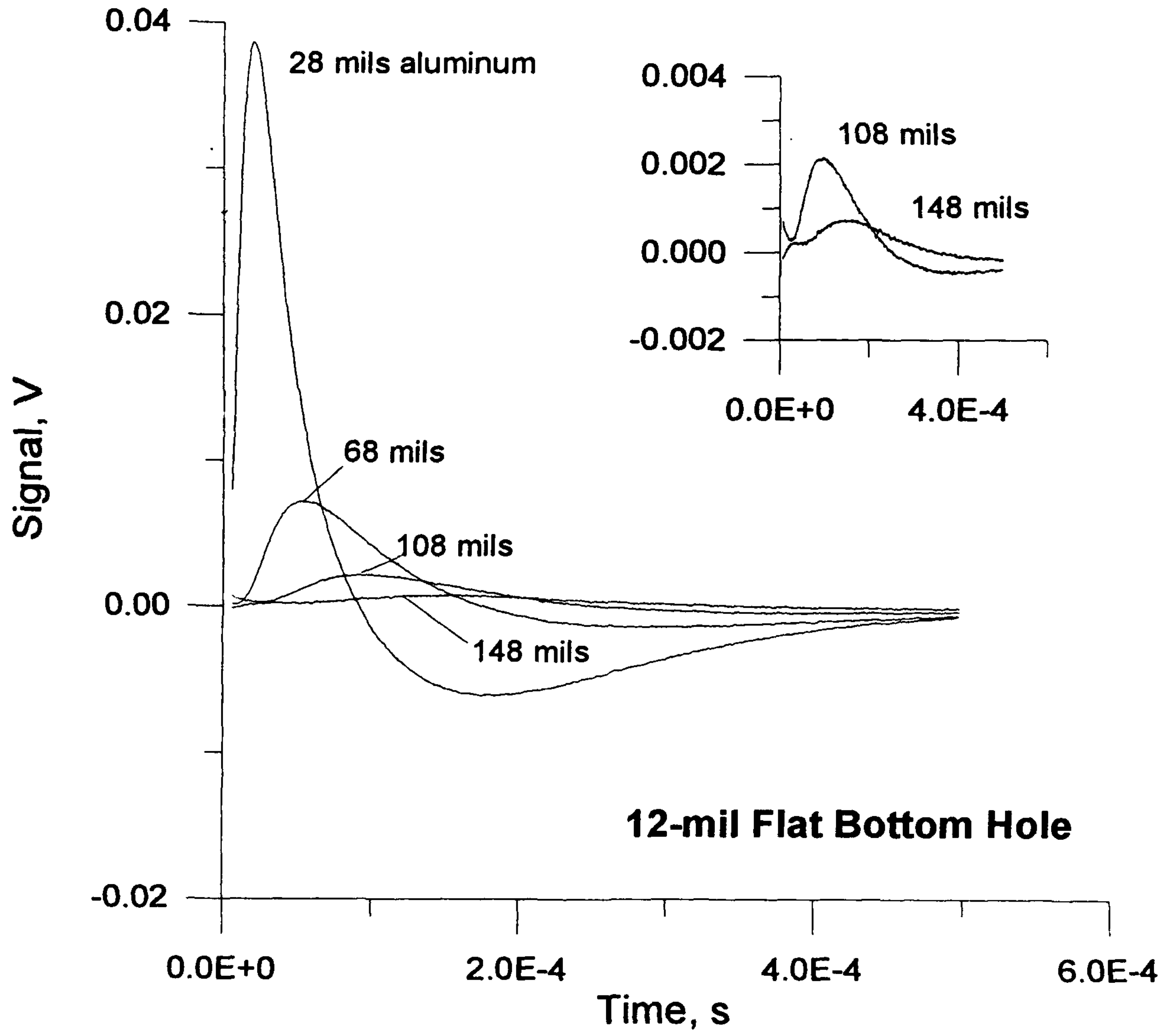
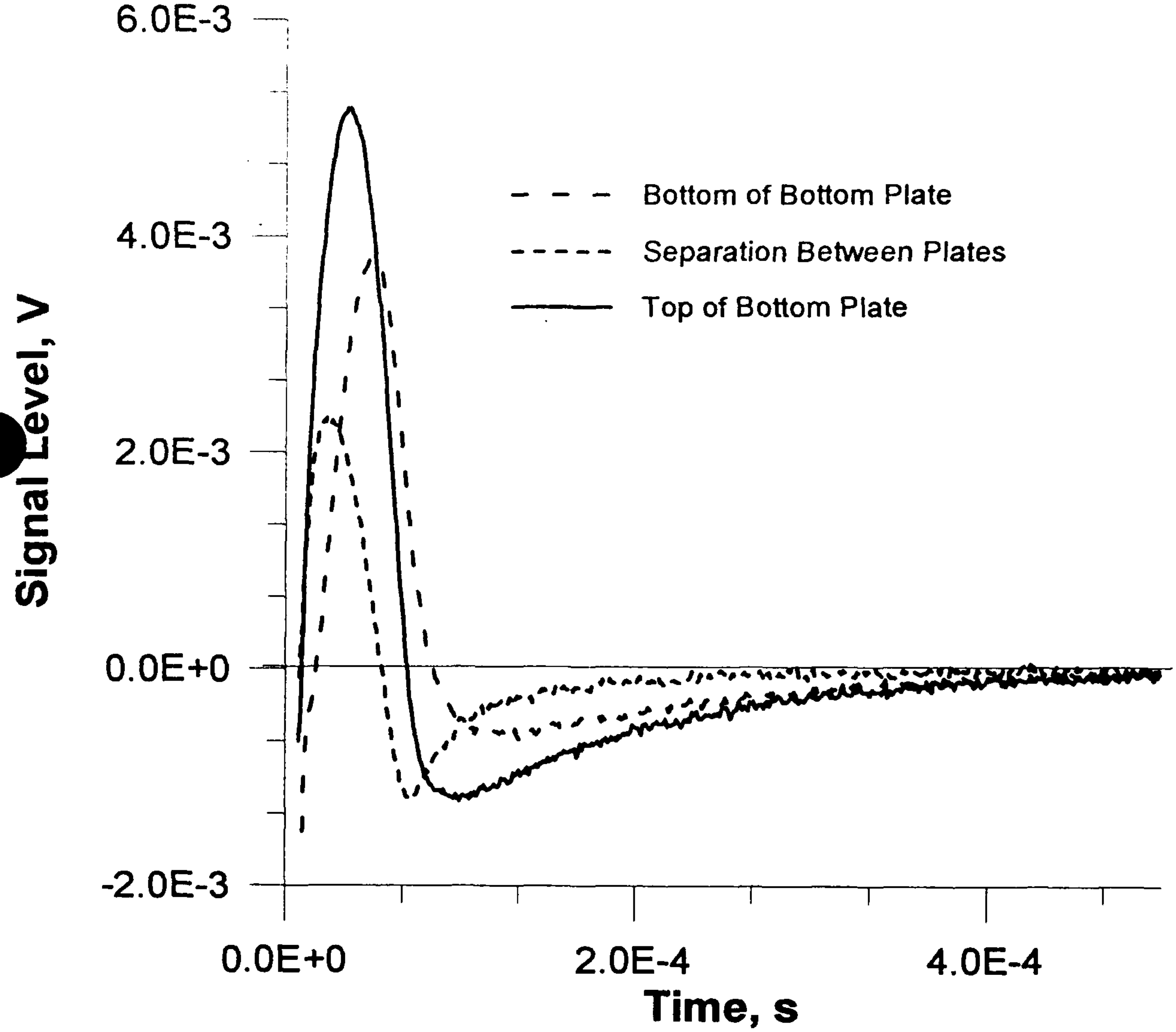
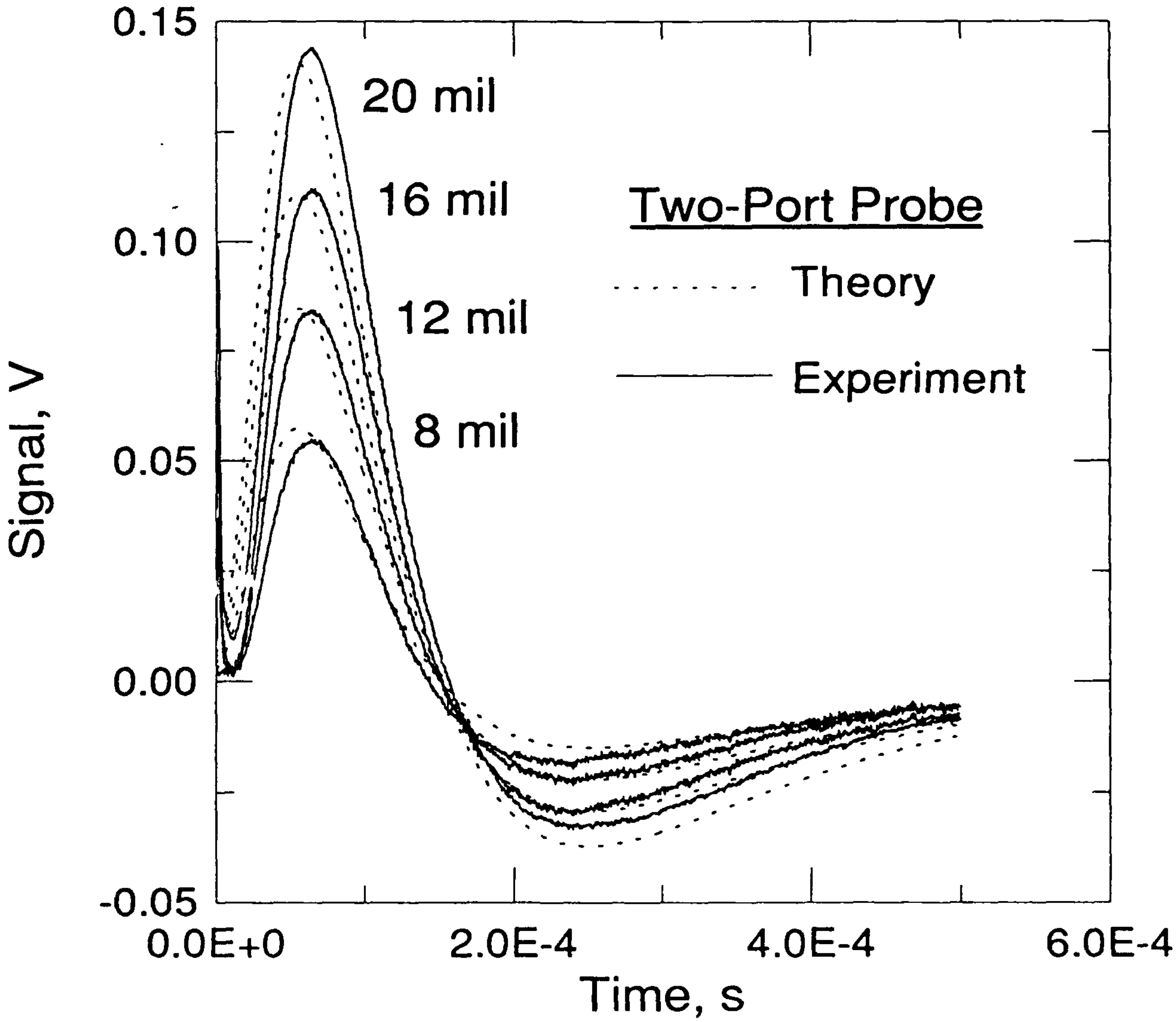


Plate Separation Compared to Simulated Corrosion (4 mils)



Pulsed Eddy Current Theory and Experiment

Simulated Corrosion in Second Layer



NDI for Corrosion Detection RPI 205

FAA Center for Aviation Systems Reliability

Task: **Eddy Current Methods for Corrosion Detection**

Future Directions:

- Complete adapting swept frequency method to commercial equipment
- Complete testing of Pulsed EC Prototype on simulated corrosion
- Test Pulsed EC Prototype on corrosion samples
- Correct any problems identified in testing phase
- Develop signal analysis techniques to empirically determine corrosion loss
- Adapt new theoretical developments as they become available
- Plan for transition of technology

FAARSV ISU 4-94

NDI for Corrosion Detection (NAARP-NDI4) RPI 199

FAA Center for Aviation and Systems Reliability

Project:	Techniques for Flaw Detection
Task:	Radiographic Methods for Corrosion Detection
Principal Investigators:	J. D. Achenbach and L. Lawson
FAA Sponsor:	Richard Yarges
FAA Technical Monitor:	Chris Smith
Industrial Contacts:	Delta All Nippon Airlines Swiss Air Boeing American Airlines

NDI for Corrosion Detection (NAARP-NDI4) RPI 199

FAA Center for Aviation and Systems Reliability

Task: Radiographic Methods for Corrosion Detection

Objectives: To develop an X-ray backscattering depth profilometry system for the detection and characterization of corrosion in multi-layered aircraft structures

Deliverables: A prototype X-Ray BDP system

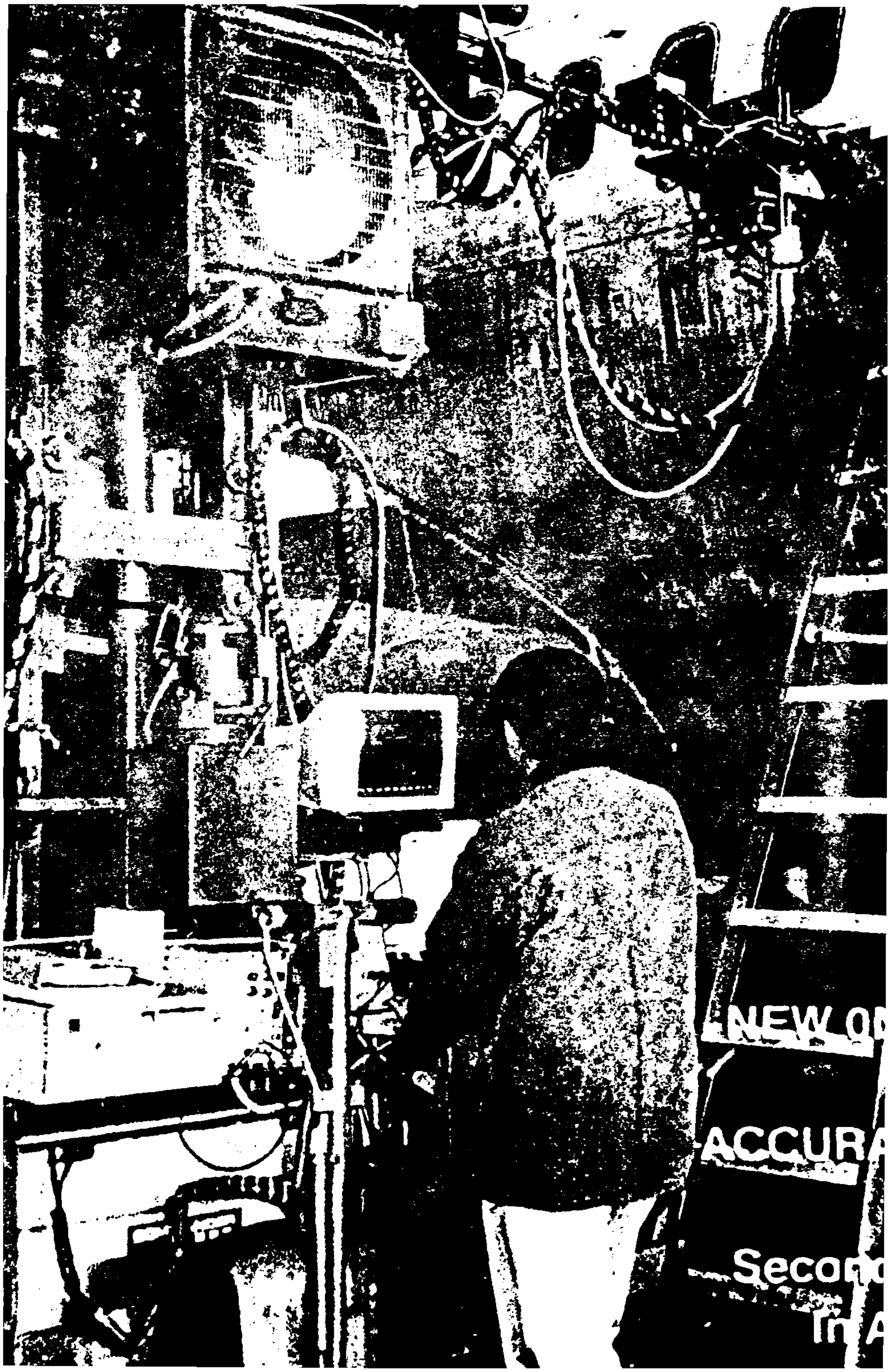
Studies of several applications of the system

NDI for Corrosion Detection (NAARP-NDI4) RPI 199

FAA Center for Aviation and Systems Reliability

Accomplishments:

- X-Ray BDP system developed in laboratory
- Technique successfully tested on coupons from aircraft
- Second-layer thickness measurement accuracy of ±0.001 inch achieved
- Prototype of mobile unit completed
- Validation testing at FAA/AANC (December 7-10,1993)
- Brochure mailed (March,1994)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FEATURES OF COMPTON X-RAY BACKSCATTER DEPTH PROFILOMETRY

- Gives a cross-sectional view of aircraft sheet metal joints.
- Allows dimensional measurement and material identification of sub-surface layers.
- Only one-sided access needed. Not a transmission (shadow casting) technique.
- 1/1000 inch measurement accuracy.
- Generates very little stray x-radiation.
- No evacuations. Does not interfere with hangar activity.
- Self-propelled. Scaffolding and stands are not needed.
- Data are digital files. Easily stored and transmitted via Internet.

Summary

This report briefly describes the Concept, the Equipment and the Preliminary Validation of an X-Ray Backscattering Technique to obtain quantitative thickness profiles of layered aircraft structures for the purpose of detecting and characterizing second-layer corrosion.

This technique was developed and the prototype was built by Dr. Lawrence R. Lawson at the Center for Quality Engineering and Failure Prevention at Northwestern University . This project was funded by the Federal Aviation Administration as part of CQEFP's participation in the Center for Aviation System Reliability Consortium. A patent disclosure has been filed.

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WHAT IS X-RAY BACKSCATTER DEPTH PROFILOMETRY?

Compton x-ray backscatter depth profilometry , abbreviated X-Ray BDP, is a digital imaging technique for examining cross-sections of layered structures. It is based on the backscattering of x-ray photons toward a detector. The technique was developed specifically for the inspection of aircraft structures for corrosion as seen in the cover illustration. Unlike conventional radiographic techniques and CAT scanning, it is not a shadow-casting technique. The important difference is that X-Ray BDP gives a true *cross-sectional* view of the object being examined while in conventional (transmission) radiography, all information on structural features within the beam is superimposed in a single recording. The other major difference is that, unlike conventional radiography, X-Ray BDP does not require access to both sides of the object being examined. It can perform inspections of aircraft structures from the outside of the plane.

X-Ray BDP is designed to provide a highly accurate depth profile in locations of interest. It eliminates the costly down time needed for rivet removal required for direct measurement with calipers. It also eliminates the potential for fatigue crack initiation caused by bending the sheet metal in order to get the calipers in place or make a visual inspection. A point measurement technique such as X-Ray BDP is needed when there is an indication of corrosion by pillowing or some other broad-area inspection method such as eddy current scanning, ultrasonic scanning or possibly thermal wave imaging. These methods give a 2-D map of the near sub-surface region quickly, but they have not been able to generate cross-sectional views of much accuracy nor depth profiles. X-Ray BDP gives that additional information about thickness which is needed to make the decision of whether or not repairs are needed -- and how soon.

To collect backscatter data, the special depth-profiling camera shown in figure 1 was developed. The camera, which includes the x-ray tube, consists of a radiation detector and a precision anisotropic collimation system for both the source and the detector. Four apertures define collimation, as shown in figure 1. The first two form the beam into a pencil with a narrow rectangular cross-section. The second two apertures select a limited-thickness region from which backscattered photons reach the detector. The selected backscattered beam falls upon a thallium-doped sodium iodide scintillation detector placed outside aperture 4. The intersection of the incident and backscattered beam paths forms a scattering zone. Sweeping this scattering zone through the structure to be examined allows visualization along the path of the electron density of the material, which for aluminum and lighter elements is proportional to their mass density . The camera is mounted on a positioner which scans it in a direction perpendicular to the surface of the structure.

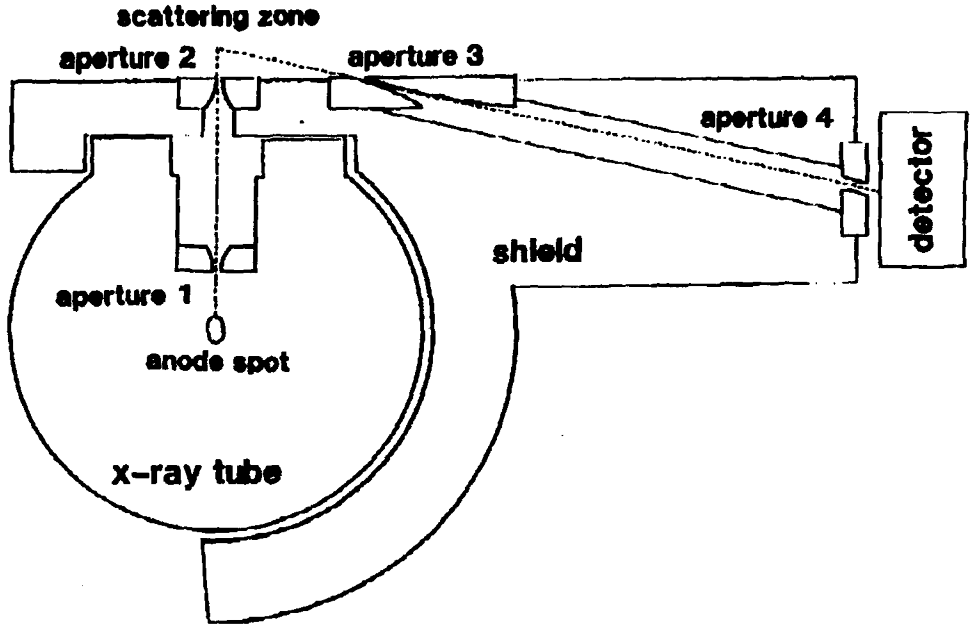


Fig. 1 Schematic representation of the backscatter camera

Like in other backscattering methods, the X-Ray BDP equipment could be used to generate 3-D images of entire volumes of material. Such an approach would, however, be very slow. In order to maximize the utility of backscatter data for aircraft inspection, X-Ray BDP reduces the image to one dimension. This makes the acquisition time on the order of 10 minutes per image--a practicable amount of time. The resulting image may be thought of as that of a core-drilled sample taken through the structure. The term "virtual core drill" has been coined to describe the X-Ray BDP machine for this reason. The design of the X-Ray BDP apparatus takes advantage of this limited dimensionality to obtain higher flux for a given resolution than could be obtained with a conventionally-designed backscatter imaging system. The shape of the scattering zone is made anisotropic and the beam angles are correspondingly chosen to maximize the flux.

The resolution of the X-Ray BDP system has been chosen to measure the thickness of the layers of aircraft skin with an accuracy of ± 0.001" which is about that of a common grade of dial caliper. This is near to the best accuracy obtainable when measuring metal which has not been polished smooth. Manufacturing tolerances, and of course corrosion, both limit the smoothness of real surfaces. Furthermore, measurement errors typically add quadratically on the average. Thus if a micrometer having a ± 0.001 inch accuracy were used to measure a surface having 0.001" roughness, than the average measurement error would be ± 0.0014". This is not the best accuracy possible with the X-Ray BDP technique but is close to the best meaningful accuracy possible since surface roughness less than ± 0.001" is not typical for most surfaces on aging aircraft structures.

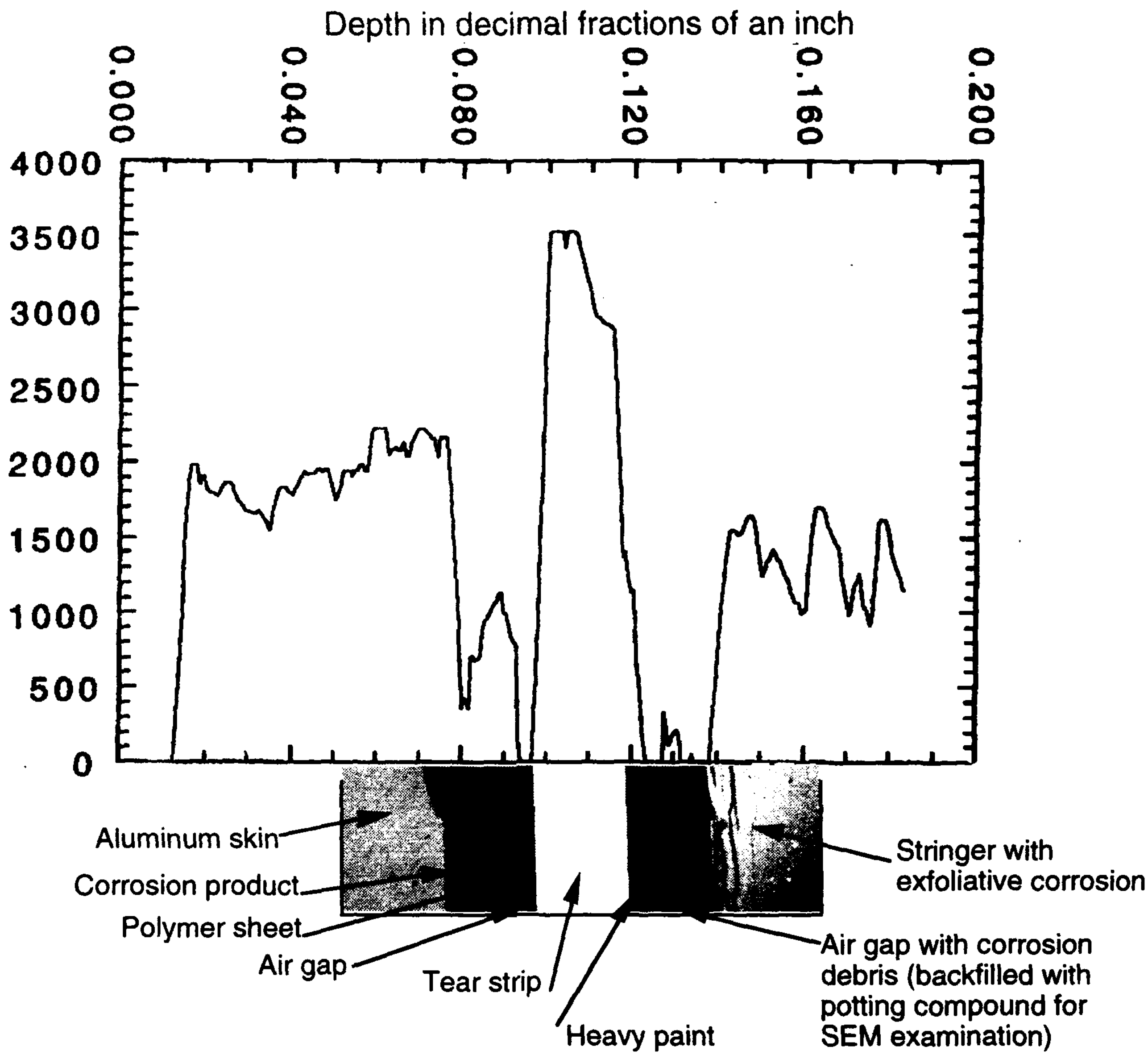


Fig. 2 Comparison of an X-Ray BDP scan, above, with an electron mucrograph, below, of a cross section of an aircraft sheet metal joint.

X-Ray BDP reveals the details of layered aircraft structures. Figure 2 shows a comparison of an X-Ray BDP scan with an electron micrograph of a core sample drilled from the same location on a fuselage. The vertical axis on the scan represents the relative density of the material. The horizontal axis represents the depth into the fuselage measured from a point slightly above the surface at which the scan began. The electron micrograph displays the region between the outer skin and a stringer. In the scan, the outer layer, of aluminum, appears as a boxcar starting near 0.01". There follows a low-density region a couple thousandths of an inch in thick followed by a piece of plastic sheet, a faying strip, nearly 0.012" thick. Following that strip, there is an air gap. Beyond that gap, is a stainless steel tear strip. The tear strip has a higher density than the aluminum. The back side of the tear strip is painted. Beyond the tear strip is a large air gap containing corrosion debris. Then follows the the stringer. The paint on the back side of the tear strip is discernible. The stringer appears to be less dense than the skin, which is the result of iron in the tear strip exerting a shielding effect on layers beneath it. The presence of the heavy element, iron, in the tear strip can be deduced from the tilting down to the right of the top of the tear strip's boxcar while those of aluminum are flat.

Indications in a scan of unexpected low-density material, air gaps and thinning of metal are the hallmarks of corrosion in an aircraft structure.The presence of loose low density material signals active or untreated corrosion. Air gaps alone, unless greater than a few mils in width, do not by themselves indicate corrosion. Within the present field experience with X-Ray BDP, air gaps seem to be present in all joints in older aircraft. On one hand this is a benefit since it makes possible accurate determination of metal thicknesses while using larger data collection step sizes than would be otherwise allowable. But, it is the presence of these gaps which give rise to water trapping and corrosion in the first place. Corrosion products, when compacted, often appear as material having about half the density of their parent aluminum. Loose corrosion products often have still lower densities.

The corrosion process itself appears to determine the relatively low density of corrosion products as seen in X-Ray BDP. Water typically collects in small gaps between metal layers. Salts or other ionizable species from waste products, air pollution, ocean spray etc. find their way into the water. Chlorides appear to be especially detrimental. Sometimes ions of more noble metals such as copper also get into the joint . These can set up local electric currents which dissolve the aluminum much as the anode of a battery. More often the water and the thinness of the gap prevent air from entering uniformly. The parts of the gap that are deep inside become anodic due to the relative lack of oxygen and this sets of electric currents which dissolve the aluminum in these recesses. This process is called crevice corrosion. In all cases, ions must move through the corrosion product layer to support the electric current. This means that all corrosion products must be porous in order to grow. Their pores are the primary reason that corrosion products are less dense than aluminum itself. Figure 3 shows an electron micrograph of undisturbed corrosion product on the surface of a second-layer of skin. The relative volume of pores is 40%. The pores are the channels for the corrosion current to flow. Without pores, the corrosion product would be protective films since oxides and hydroxides are, by nature, insulators and ions cannot diffuse through them directly at temperatures below about 1000°C.

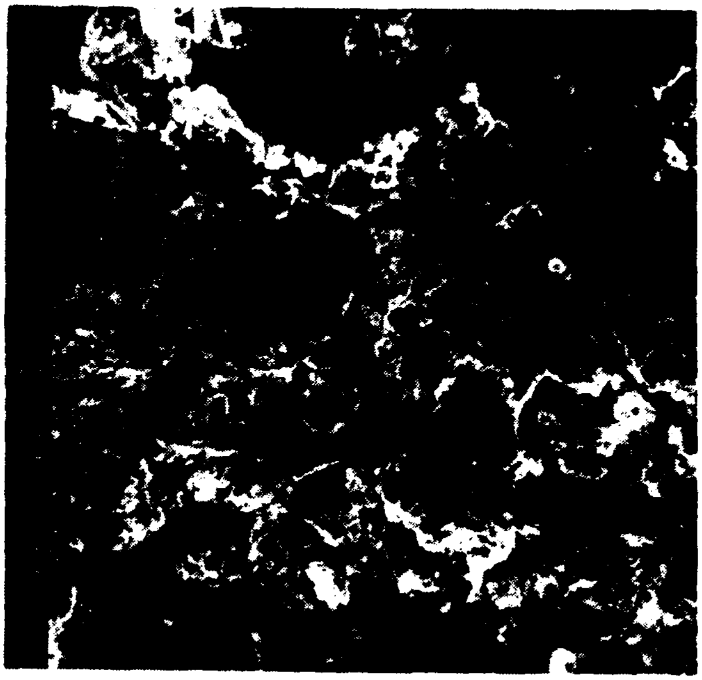


Fig. 3 Corrosion product on the surface of a second-layer of fuselage skin

HOW DO YOU USE X-RAY BDP?

The cover illustration shows X-Ray BDP being used to inspect a station along a lap splice on the Boeing 737 located at the FAA/AANC facility in Albuquerque, NM. The X-Ray BDP unit moves around under its own battery power. The unit is positioned at the point where the scan is to take place, and the scan head is guided to the exact location by an operator (typically on a ladder). The operator controls the boom and can pivot the scan head. When the scan head is in place, four feet rest against the planes surface. Then by operating the boom, the scan head is pressed against the plane. Friction of the feet against the surface holds the scan head in place. The boom itself is a giant spring which is constructed so as to have compliance in the axial as well as lateral directions. The boom supports the scan head and simultaneously applies pressure normal to the bottom surface of the scan head's feet in whatever position the head may be placed. The cover shows the scan head being pressed against the side of the plane. Figure 4 shows the scan head lifted into position for inspection of the belly section of an aircraft. The scan head when in use is thus aligned with the surface of the plane and sufficiently independent of the motorized carriage, which transports it.

Once in place, the scan head is precisely re-aligned by computer-controlled stepper motors using position sensors which contact the plane; and, then the scan begins. Figure 5 shows the scan head. One of the motors is visible in the lower foreground; two of the four feet are seen at the

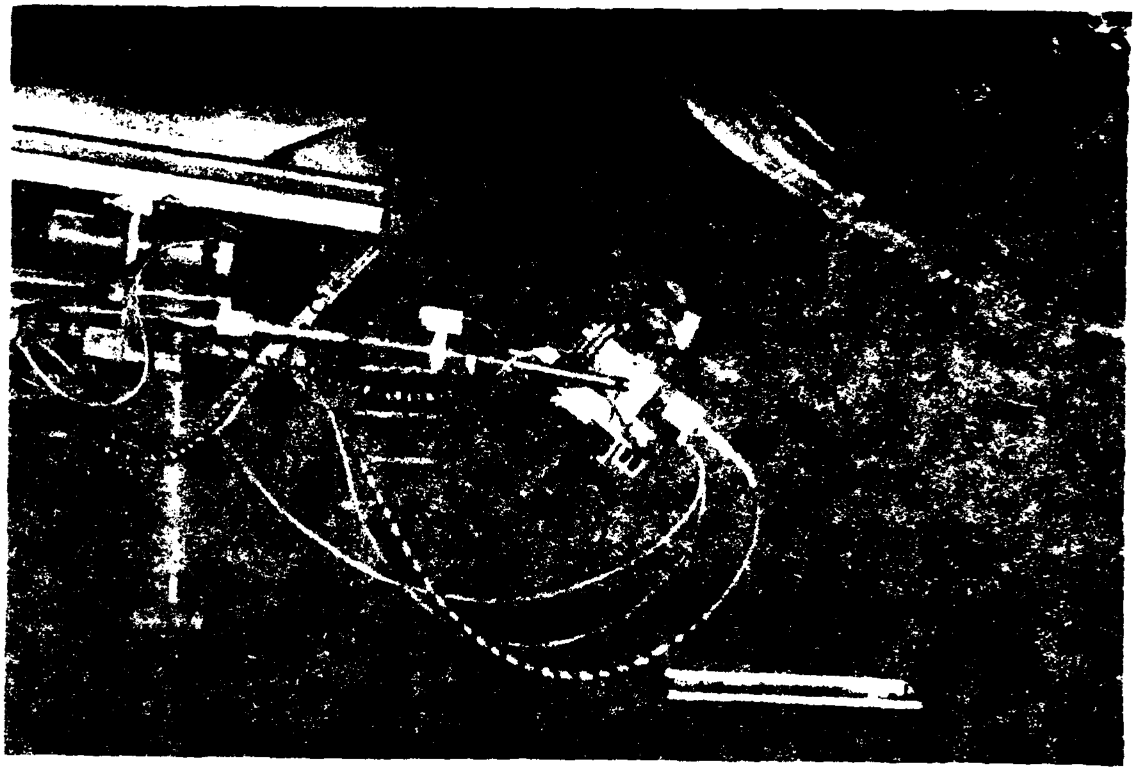


Fig. 4 X-Ray BDP Scan in place underneath an aircraft for scanning the belly section

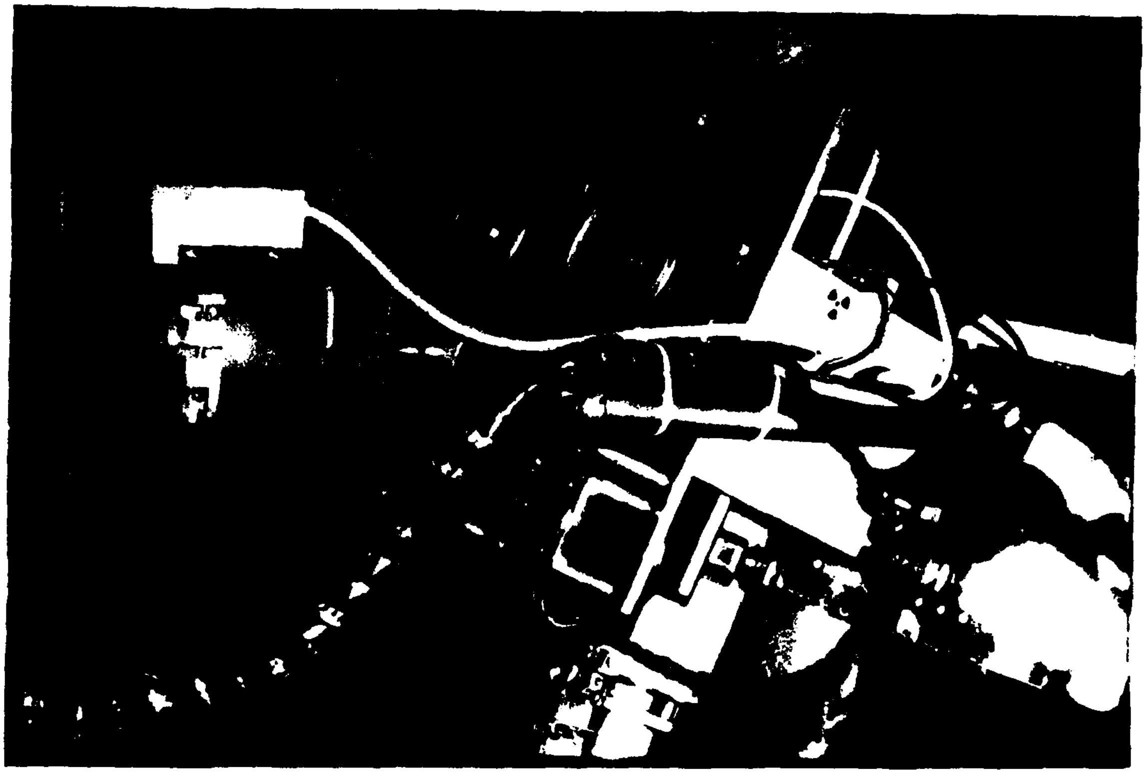
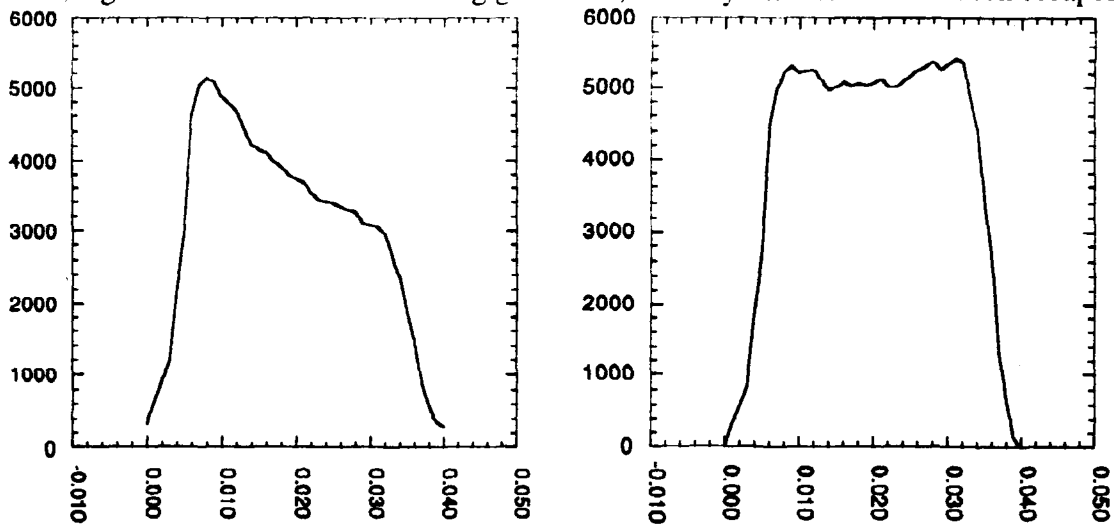
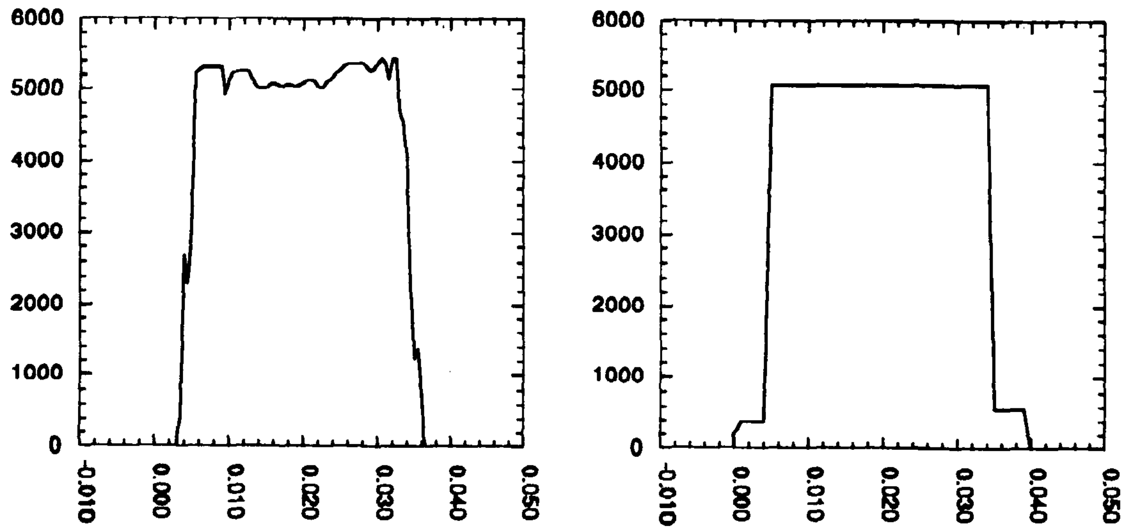


Fig. 5 Scan head. One of the stepper motors and two of the feet are visible.

right. The computer performs the scan, advancing the motors and stopping at intervals to collect data. These intervals are steps of usually 0.001" or 0.002". Because an edge appears as a slope in the unprocessed data, the edge can be precisely located so long as two data points are taken along the slope. Thus, for example, in principle, a 0.002" step will precisely locate an edge(within say 0.0001") provided that there is a gap of 0.004 or more inches between that edge and the next one. Of course, noise degrades this precision and the main source of noise is the statistical nature of photon counting. As a rule of thumb, 1000 counts are needed to locate the edge in the example to within 0.001". Increasing the number of counts increases the precision. While the scan is being made, the x-ray tube is operated typically at 150 KV and 15 mA. This means that, within the tube, a great deal of radiation is being generated, but very little of this radiation escapes. Only a



Figs. 6a,b Raw(a) and reconstructed(b) data for a scan through a single layer
The x-axis is depth in decimal inches, the y-axis is relative density.



Figs. 6c,d Deconvolved(c) and blocked(d) data.

very tiny beam is actually used. Heavy shielding near the x-ray tube is needed to confine the beam. Consequently, very little radiation escapes into the environment. During scanning, the radiation level is low enough that, by the standards of most States, workers who are not designated radiation workers may safely approach within as little as three feet from the operating x-ray tube. Greater than ten feet from the operating tube, the radiation level is extremely low. Mechanics may thus work on the outside of the plane in the vicinity of X-Ray BDP scanning. Because some of the beam becomes trapped inside, working inside the plane during scanning might be inadvisable. But the worst dose of radiation measured on the inside of a plane, directly on the other side of a fuselage skin at the point of irradiation, still amounted to only the equivalent of one chest x-ray per hour. During the scanning, the computer rechecks alignment and realigns the scan head as needed. If the count rate drops to too low a value, the computer interrupts the scan and queries the operator for instructions.

When the scan is completed, the computer displays the result as a graph similar to that in figure 2. Several processing steps are involved. These are illustrated in figures 6a-d. Figure 6a shows the raw data for a scan through a single piece of metal. The effect of reconstruction is shown in figure 6b. Reconstruction mathematically removes the shadows of upper layers on lower ones. In the case of a single layer it converts a boxcar with an exponential top, figure 6a, into one with a flat top, figure 6b. The next step removes the blurring effect of the aperture upon edges. This blurring effect gives sloping sides to the boxcars in figures 6a and 6b. Figure 6c shows the sides squared through deconvolution. A still more idealized form is obtained by further processing called "boxing" or "blocking". Blocking applies a slope threshold method of edge finding to the deconvolved data. A table of layer thicknesses is an important byproduct of the process. Unfortunately, this type of processing slightly degrades the accuracy of the measurement. A less-speedy approach based on using the deconvolved or blocked image as a guide to finding the actual edges in the raw data gives superior results.

EXAMPLES OF X-RAY BDP

The two examples which follow were taken from scans made at the FAA/AANC Validation Center, as part of the preliminary validation process of X-Ray BDP.

Figure 7 shows a scan of a Boeing 737 at the FAA/AANC facility. The scan is taken through a lap joint along the middle row of rivets. The scan has been processed through the deconvolution step shown in figure 6c. Large air gaps and loose material suggest the presence of corrosion. The front layer of skin measured 0.0375" using the deconvolved plot. The expected accuracy under these circumstances is an average absolute error of 0.0015". Better accuracy could have been obtained by fitting the raw da.a, as mentioned above, but this is not yet routine.

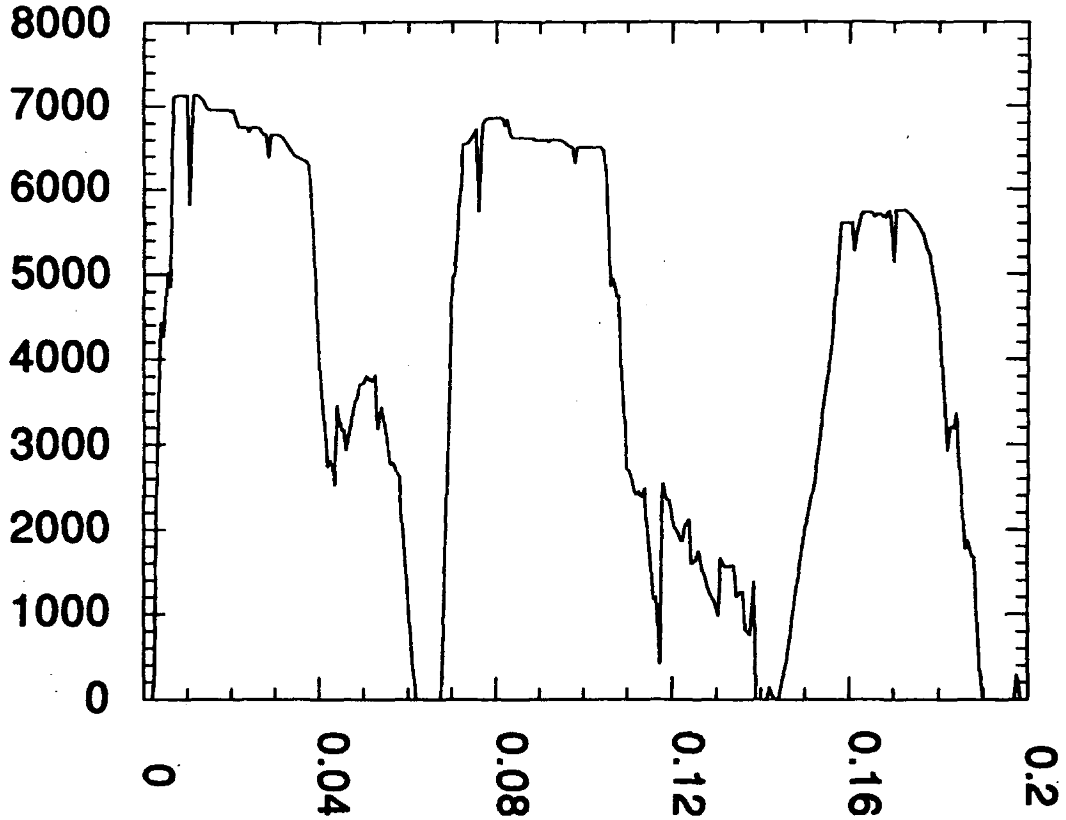


Fig. 7 Scan through a lap joint. Three metal layers are shown.

In what follows, the thicknesses will be quoted to the apparent accuracy on the scan, three or four decimal places, in order to avoid inviting cumulative rounding errors, since the accuracy of two layer thicknesses added together is still the same as that for each layer. Beneath the front layer was a faying strip of possibly scrim cloth and sealant. It resembles the layer of polymer seen in figure 2. The scan suggests that this layer has become detached from the front layer leaving a 0.001" gap. The low-density faying layer measured 0.0175". Below the faying layer was another air gap, 0.0097" wide. The second layer of skin, which begins below this gap, measured 0.0403". Its rear surface looks rough as indicated by the sloping of its front surface being asymmetrical to that of its back surface. It may also have been painted with pr:ner. A small-step long-count-time scan of just the interface could be used to resolve this issue were it important. Beneath this layer of skin are the remains of another faying strip, probably reduced to an aggregate of sealant and corrosion product. It measured 0.0212". Its unusually-low density and looseness are strong indicators of corrosion. Beneath this is yet another air gap 0.0138" wide. The last layer is the stringer itself. It measures only 0.0355". Micrometer examination within the plane showed that the stringer was indeed about this thickness.

Figure 8 shows a scan of a boron epoxy patch applied to a cold-bonded skin on the same plane. Although boron has a low atomic number, the density appears as if it were higher than that of aluminum. This is partially the result of the very low x-ray absorption coefficient of this material. The patch measured 0.0245" thick and appears to be composed of two layers of boron fiber separated by a layer of epoxy. The outer layer measured 0.013" while the second layer of patch measured 0.0105". Between the two layers was a layer of epoxy, about one mil thick. Beneath the patch at the point where the scan was made there appears to be a disbond with a gap 0.0035" wide. There also appears to be some warpage since the planes of the aluminum and the patch are not parallel at the interface. Underneath the patch is a bonded skin composed of two layers of aluminum. The first layer measured 0.038" thick while the second measured 0.0343" thick. The resin bond between the two layers measured about 0.003".

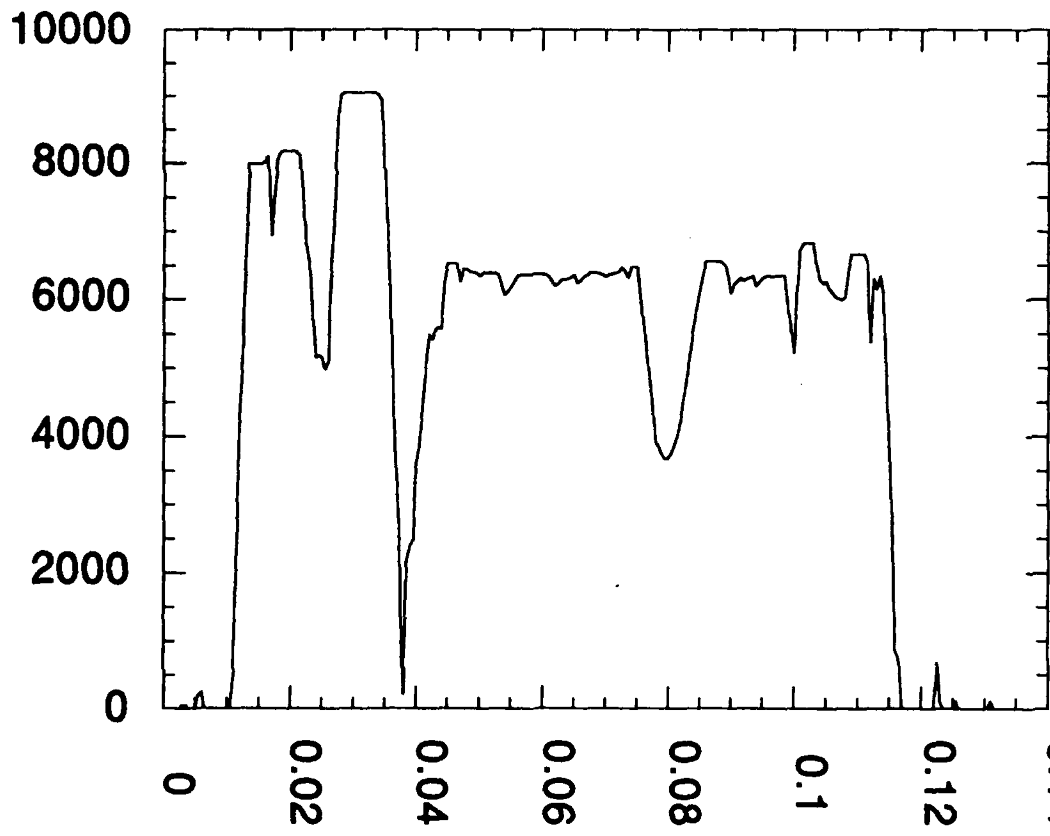


Fig. 8 Scan through a boron-epoxy patch applied to a cold-bonded skin.

NDI for Corrosion Detection (NAARP-NDI4) RPI 199

FAA Center for Aviation and Systems Reliability

Future work:

Workshop/Demonstration at FAA/AANC

Studies of further applications to aircraft structures other than skin structures and to composite materials

The Automated Non-Destructive Inspector (ANDI)

Carnegie Mellon University

April 7, 1994

Main Objective

- To demonstrate the feasibility of using robotic tools to assist aircraft inspectors
  - Robots will deploy NDI sensors
  - Inspectors will monitor robot's progress and make judgments

Project Organization

- System Development
  - Carnegie Mellon Research Institute
  - Robotics Institute of Carnegie Mellon University
- Application Expertise and Hangar Facilities
  - USAir

Project History

- Conceptual Design
  May 1991 - December 1991
  - Design and document conceptual ideas for a prototype automated inspection system

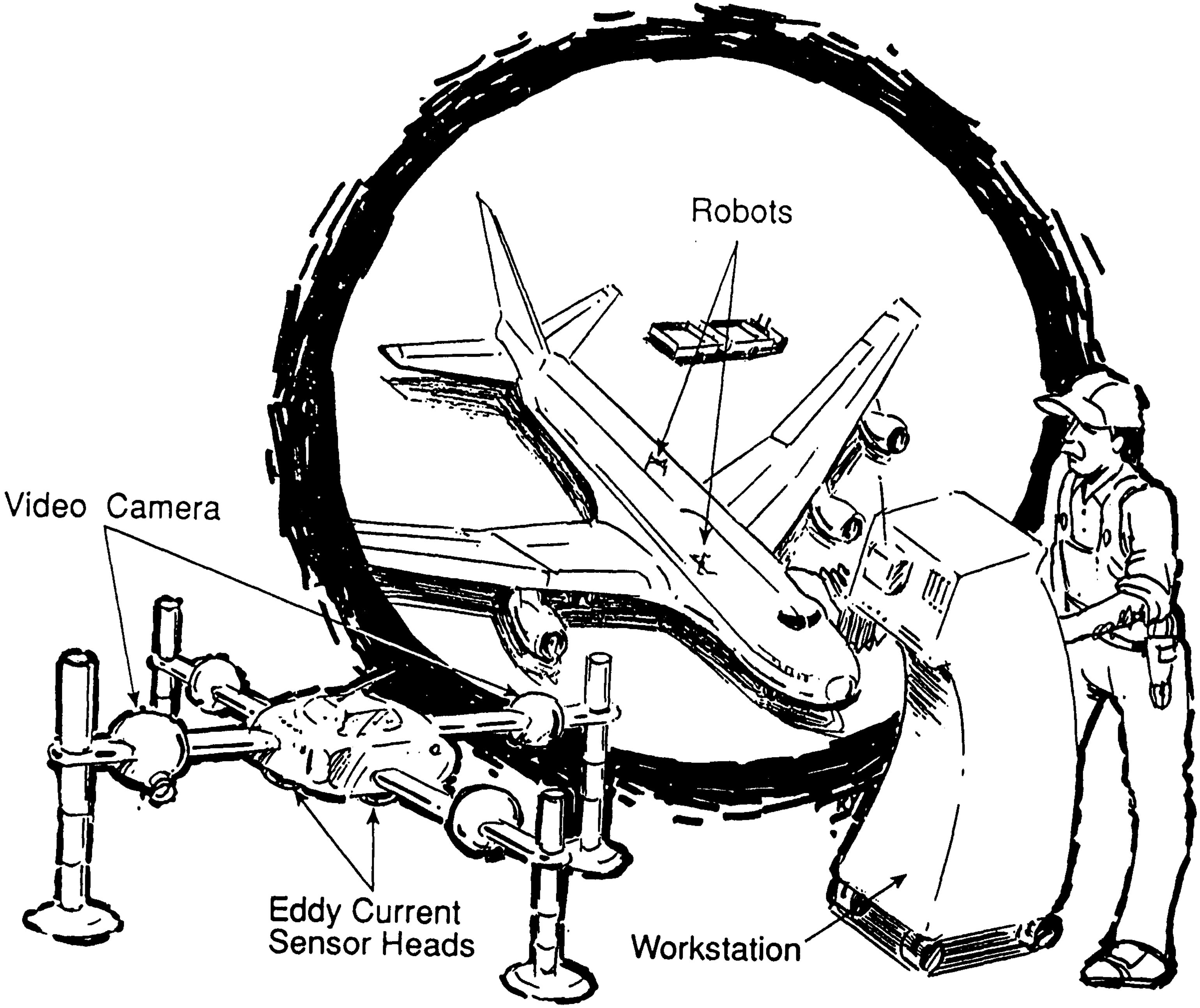
- Prototype
  May 1992 - January 1993
  - Design and fabricate basic robot platform
  - Develop basic control software

- Expanded Prototype
  February 1993 - Present
  - Design and fabricate additional robotic hardware features
  - Implement software architecture including control, navigation, and inspection software

Conceptual Design - Evaluation of Approaches

- Overhead gantry robot ("car wash")
- Ground-based robotic arm and mobile platform ("cherry picker")
- Surface-walking robot

Aircraft Skin Inspection Robot



Protoype Robot - Test Results

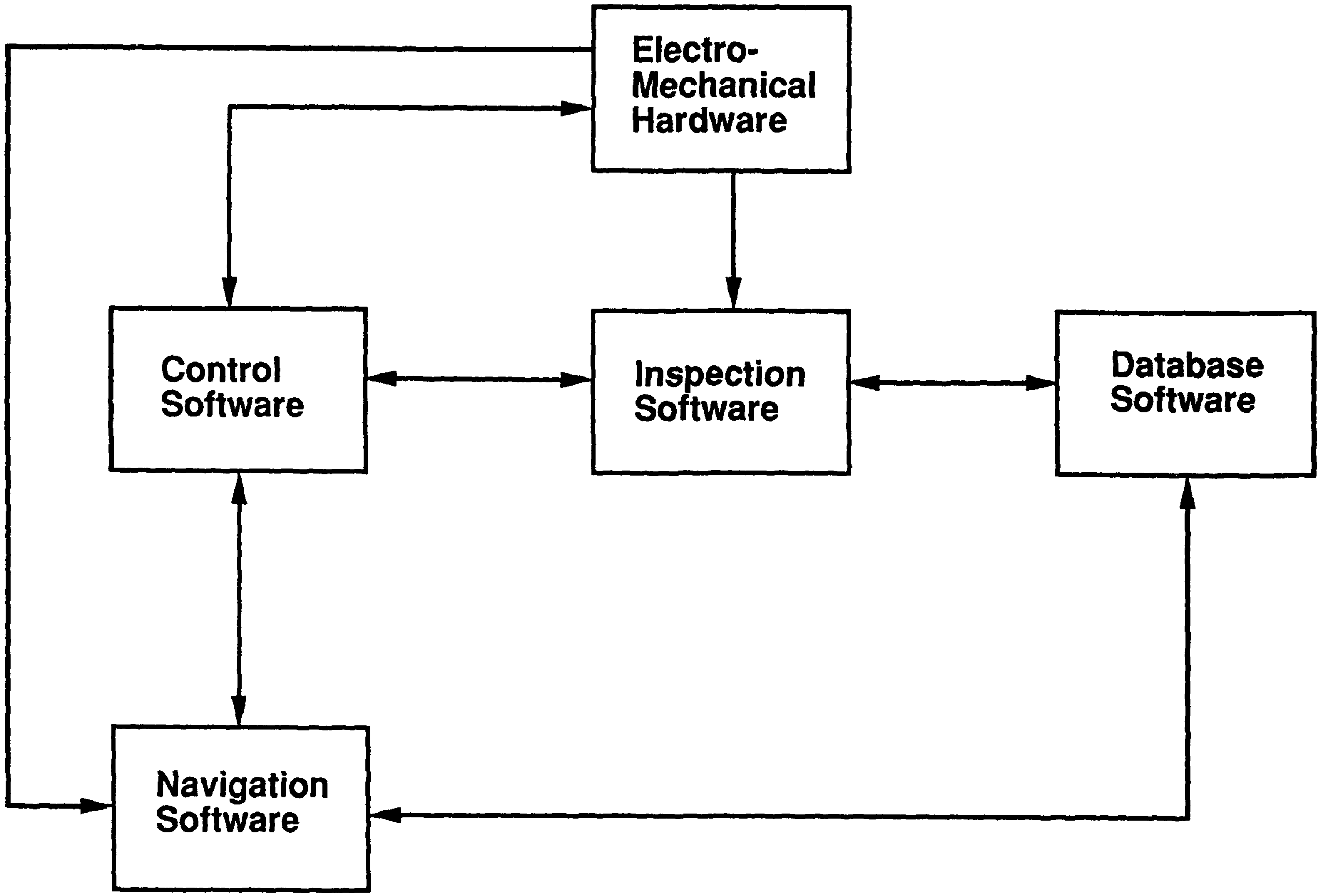
- Cruciform robot can walk on curved surfaces
- Cruciform robot can deploy an eddy current sensor on a rivet row
- Suction cups can be used to adhere to fuselage s[illegible]faces
- Size of umbilical cable must be limited

Major Components of Automated Inspection System

- Hardware
  - Physical device that interacts with the environment
    - + Actuation hardware
    - + Sensing hardware
    - + Data processing hardware

- Software
  - Modules of system that guide and control the hardware
    - + Control software
    - + Signal and image processing software
    - + Data processing, communications, and networking software

Schematic Diagram of Automated Inspection System



Robotic Sub-Systems

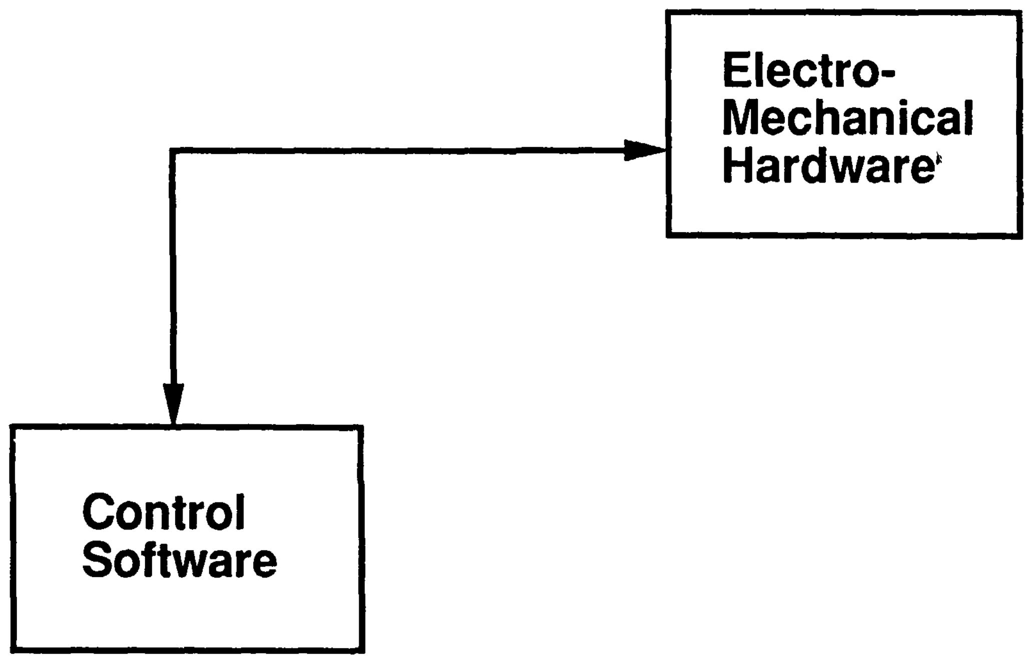
- Electro-Mechanical Hardware
  - Walks along aircraft fuselage
  - Deploys inspection sensors along rivet rows
- Control Software
  - Controls movements of the electro-mechanical hardware
- Navigation Software
  - Guides robot across fuselage surface by analyzing images from navigation cameras

Robotic Sub-Systems (continued)

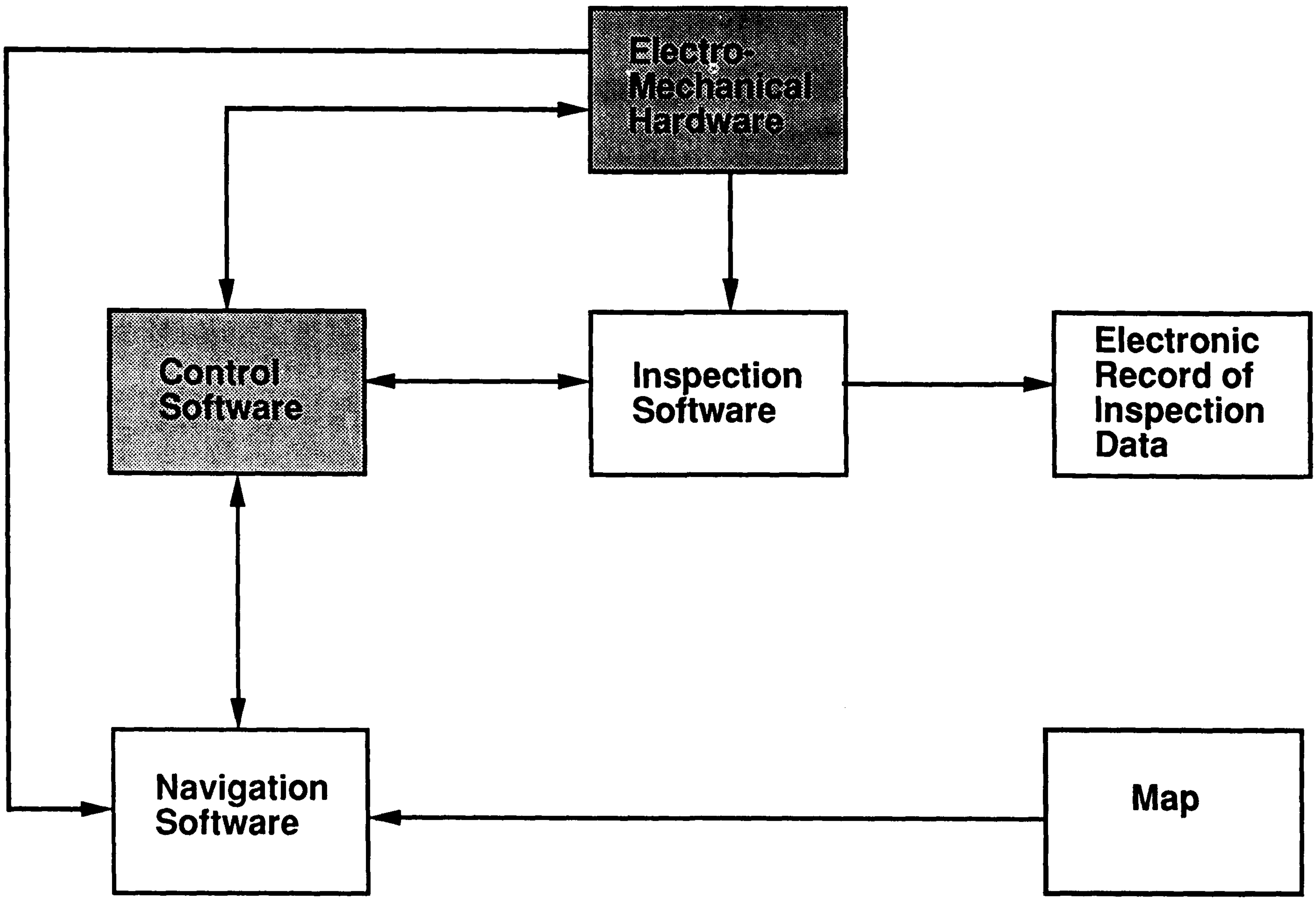
- Inspection Software
  - Analyzes data from inspection sensors
  - Controls operation of NDI instrumentation

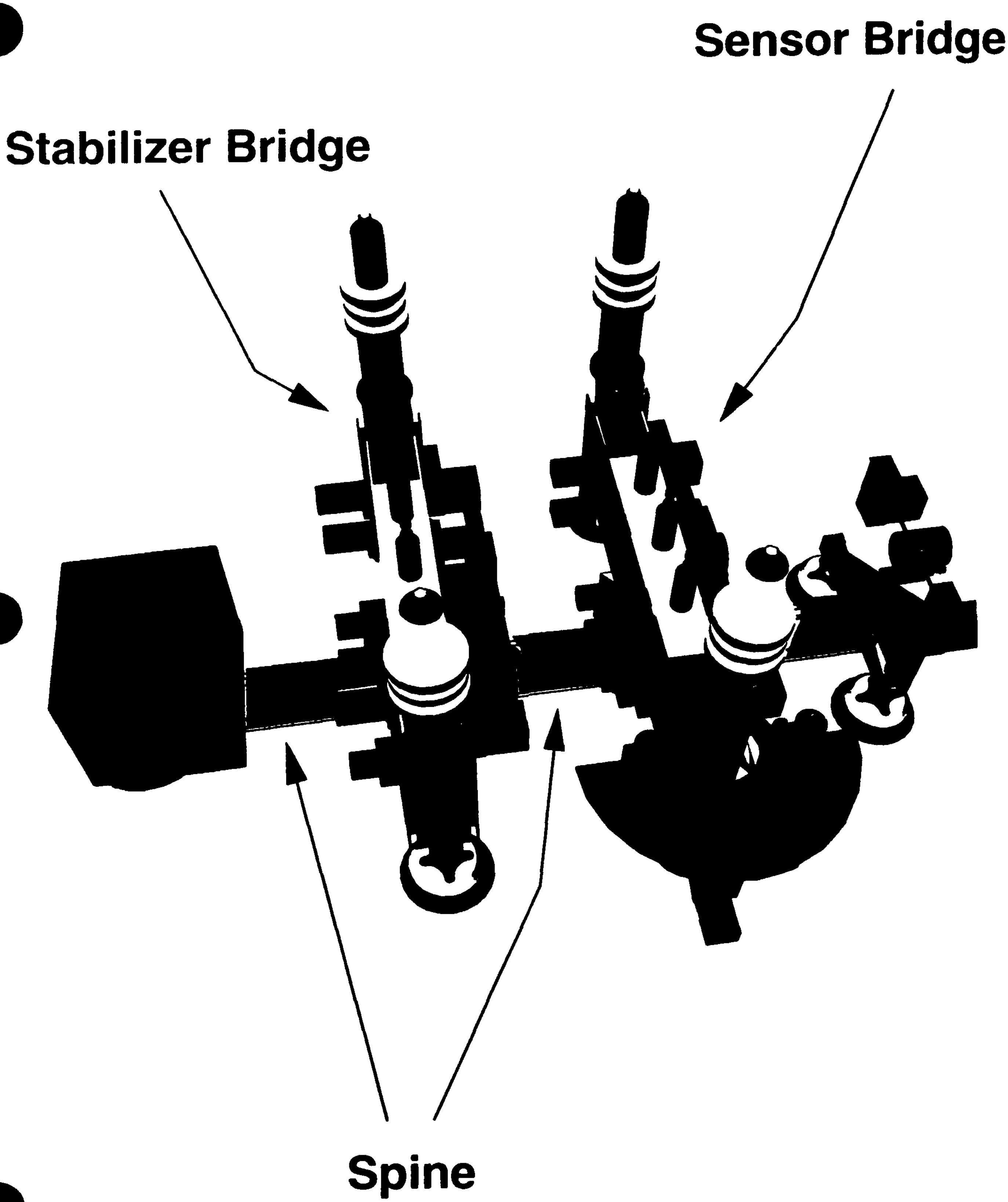
- Database Software
  - Contains maps of aircraft fuselages
  - Contains a record of flaw data

Schematic Diagram of Prototype System



Schematic Diagram of Expanded Prototype System




Sensor Bridge
Stabilizer Bridge
Spine

Robot Motions

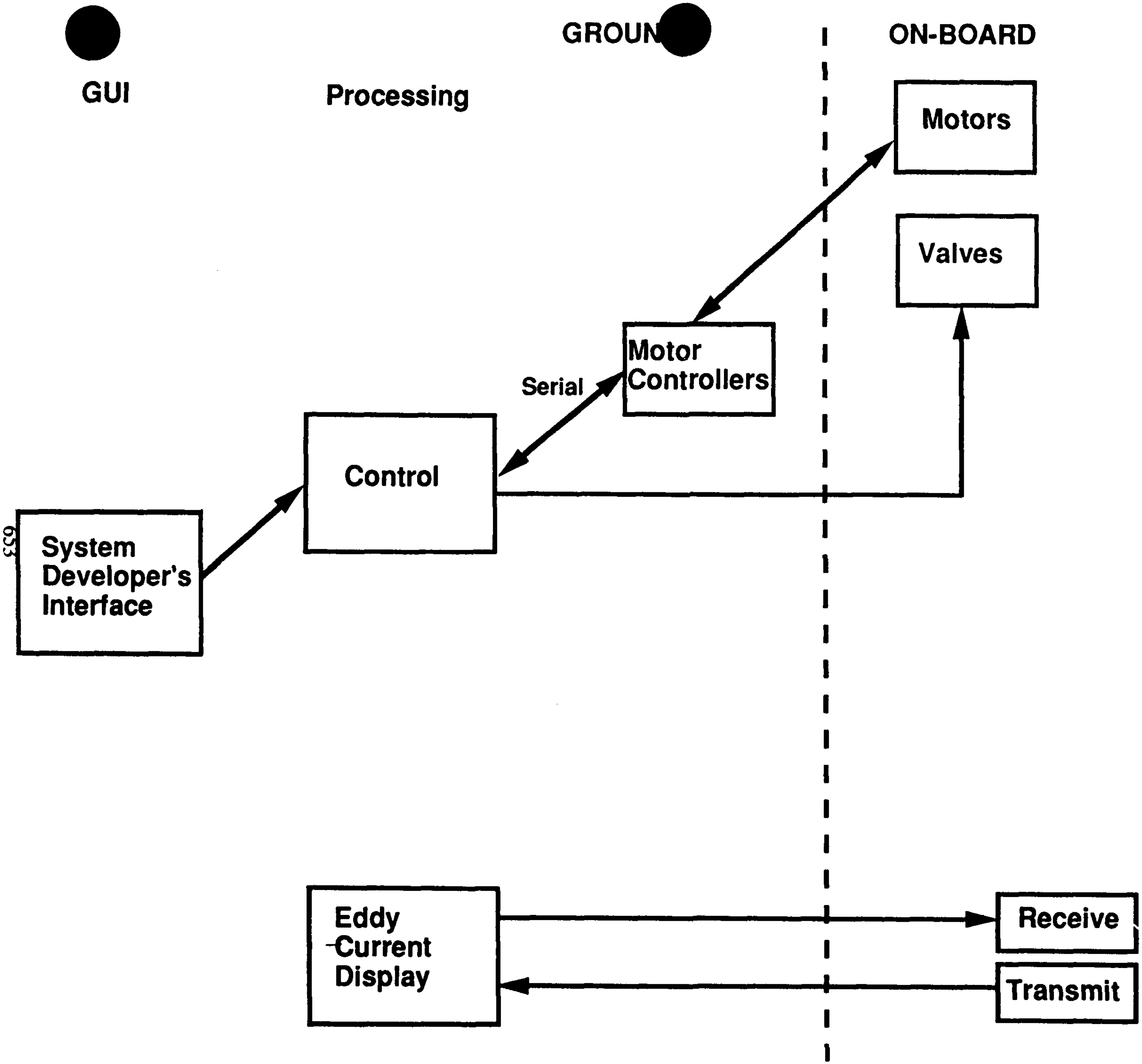
- Walking
  - Gross robot movement from one point to another
- Aligning
  - Fine movement of robot to put it into position to scan
- Scanning
  - Positioning and movement of inspection sensors

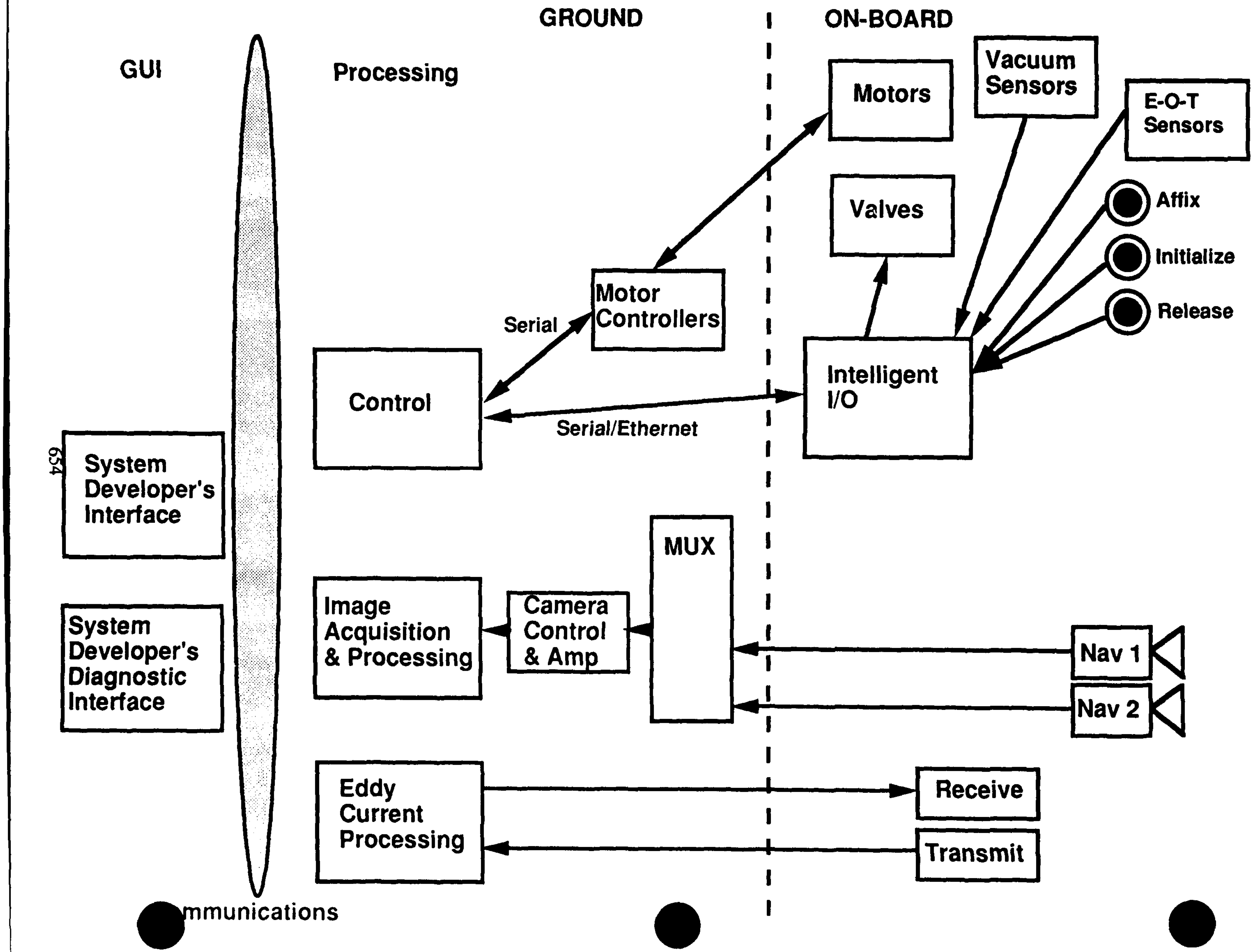
Features of Prototype Hardware

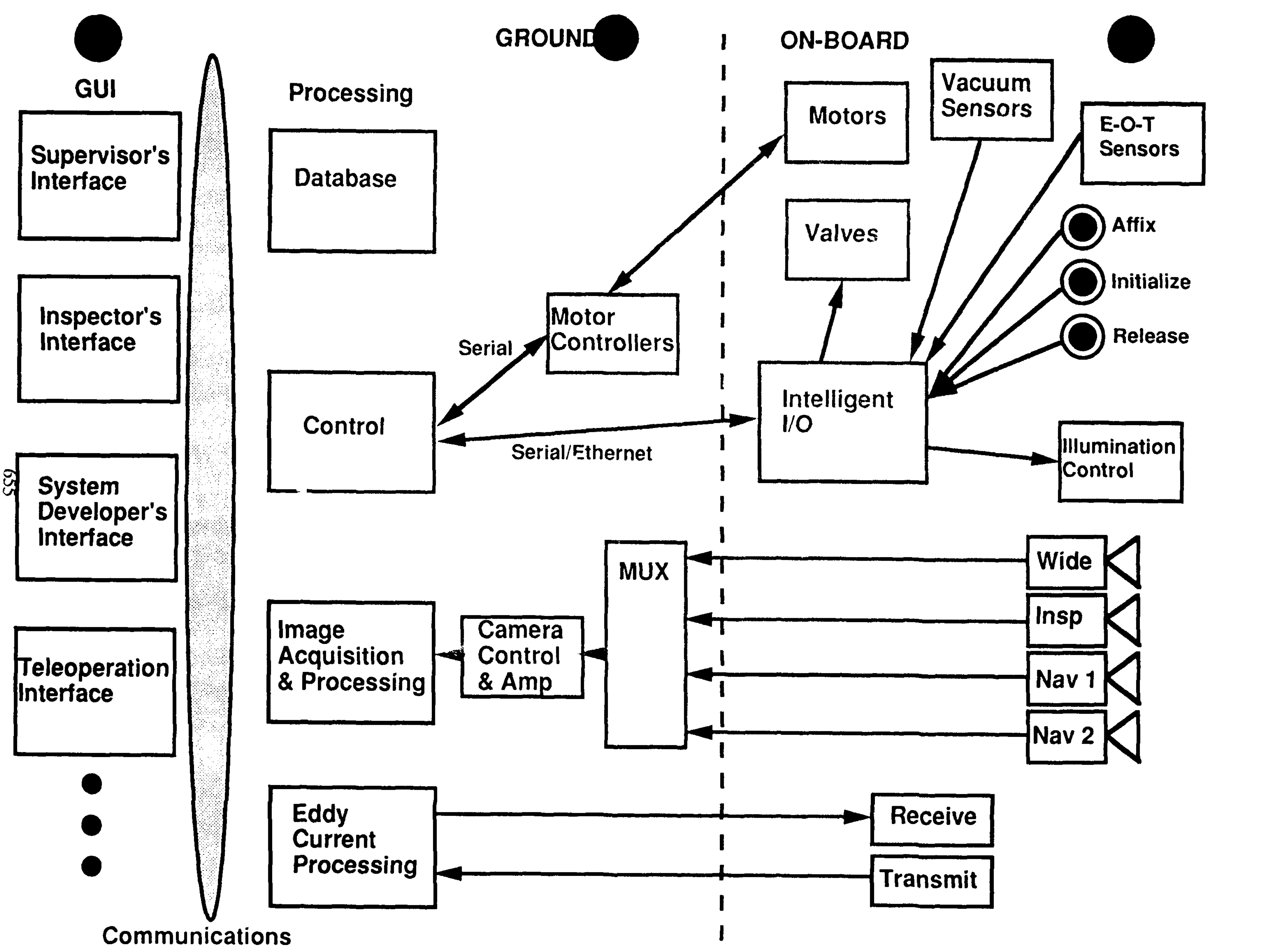
- Cruciform Design
- Suction-cup adhesion
- Eddy current inspection sensor

Features of Expanded Prototype Hardware

- Modular design
- On-board processor
- Stiffened legs
- Laboratory tether for safety
- Management of umbilical in laboratory
- Marking system
- Alignment cameras
- Sensors for end-of-travel limits

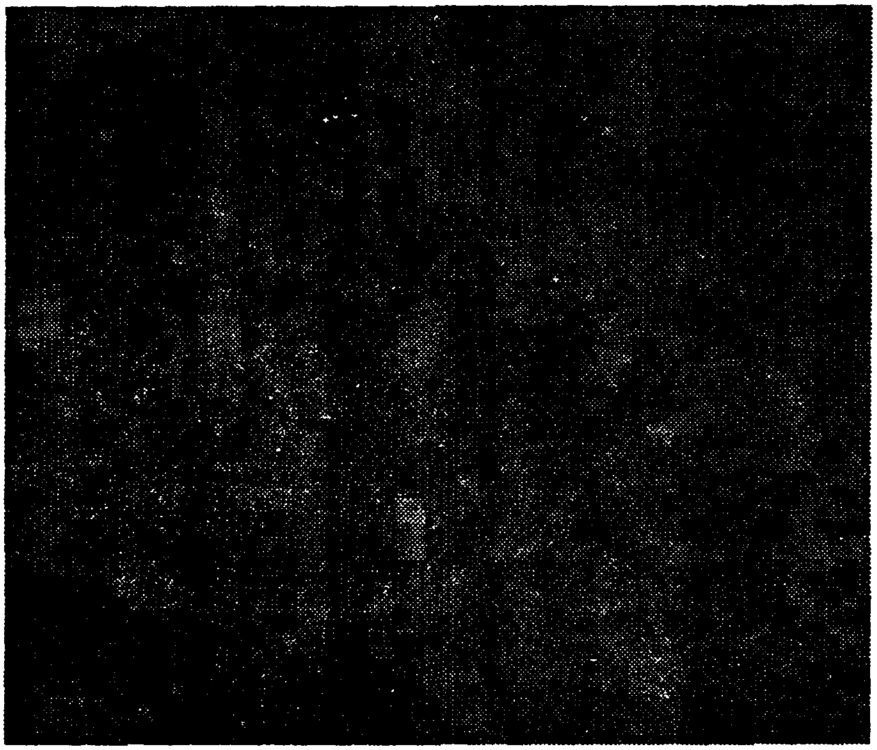

GROUND
ON-BOARD
GUI
Processing
Motors
Valves
Motor Controllers
Serial
Control
System Developer's Interface
Eddy Current Display
Receive
Transmit


GROUND
ON-BOARD
GUI
Processing
Motors
Vacuum Sensors
E-O-T Sensors
Valves
Affix
Initialize
Release
Motor Controllers
Serial
Control
Intelligent I/O
Serial/Ethernet
System Developer's Interface
MUX
System Developer's Diagnostic Interface
Image Acquisition & Processing
Camera Control & Amp
Nav 1
Nav 2
Eddy Current Processing
Receive
Transmit
mmunications

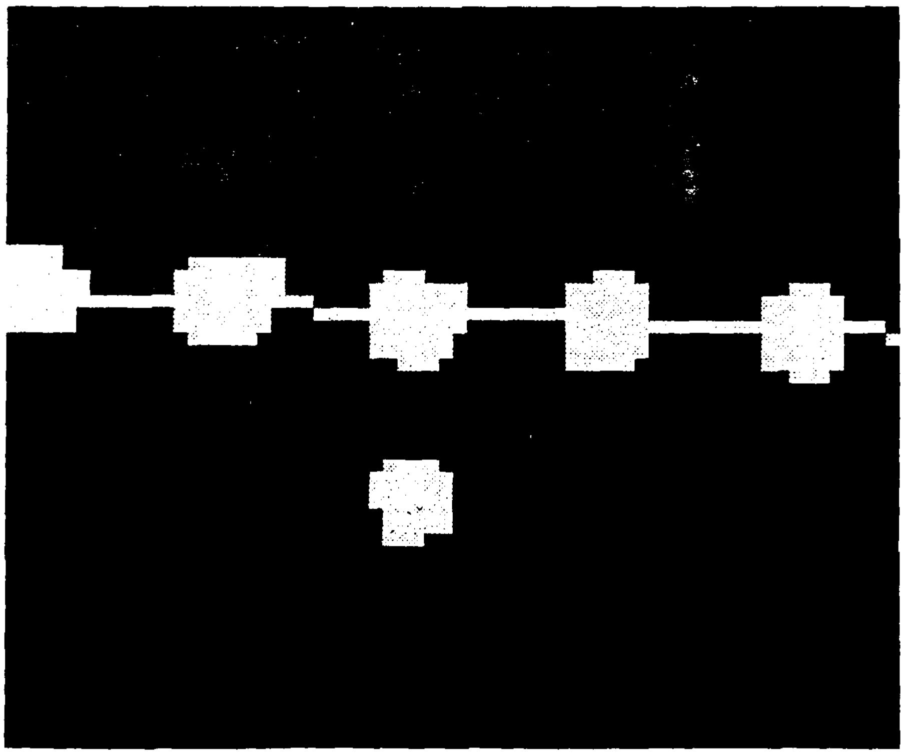

GROUND
ON-BOARD
GUI
Supervisor's Interface
Inspector's Interface
System Developer's Interface
Teleoperation Interface
Communications
Processing
Database
Control
Image Acquisition & Processing
Eddy Current Processing
Serial
Motor Controllers
Serial/Ethernet
Camera Control & Amp
MUX
Motors
Valves
Vacuum Sensors
E-O-T Sensors
Affix
Initialize
Release
Intelligent I/O
Illumination Control
Wide
Insp
Nav 1
Nav 2
Receive
Transmit

Video

Close-Up View of a Line of Rivets



edge_detect | region_grow | blob_heuristics | robust_line_fit



Expanded Prototype Testing

- Will test the robot in the laboratory using the aircraft panel set in a variety of orientations to determine the limits of the current design

- Will tests the navigation, control, and inspection software to determine the limits of the current designs

Future Work

- Iterate hardware and software designs based on laboratory testing
  - Enhance or redesign hardware or software features as appropriate

- Move towards target system architecture
  - Integrate navigation software with system
  - Add functionality to existing hardware and software modules
  - Initiate database development

- Iterate computer architecture
  - Move more hardware on board robot

Technology Transfer

- Carnegie Mellon University has a technology transfer office whose charter is to develop commercial interests

- Four companies ranging from startups to large corporations have expressed interest in commercializing ANDI

Other Related Projects

- The Transportation Center at Northwestern University
  - Economic analysis for automated inspection of aircraft
- The Wichita State University
  - Experimental analysis of robotic adhesion capabilities on inverted surfaces
- The Robotics Institute of Carnegie Mellon University
  - Development of three-dimensional stereoscopic enhanced visual inspection techniques
- The United States Bureau of Mines
  - Development of animation/simulation capabilities for Carnegie Mellon's ANDI project

Reliability
RPI 205

FAA Center for Aviation Systems Reliability

Project:	NDI Reliability
Task:	Neural Nets for Signal Classification
Principal Investigator:	L. Udpa, M. Peshkin, S. S. Udpa
FAA Sponsor:	Fred Sobeck
FAA Technical Monitor:	Dave Galella
Industrial Contacts:	NWA, AlliedSignal Engines, B.F. Goorich ABS

FAAREV IBU 4-94

Reliability
RPI 205

FAA Center for Aviation Systems Reliability

Task: NDI Reliability

Objective: Design and develop a neural network based system for the analysis and interpretation of aircraft inspection signals.

Design measures for evaluating performance of the classifier

Deliverables: A stand alone PC-based signal processing and classification system for wheel inspection that can be integrated into existing commercial wheel inspection system.

A stand alone PC-based signal processing and classification system for engine fan disk inspection.

FAAREV ISU 4-94

Reliability
RPI 205

FAA Center for Aviation Systems Reliability

Task: NDI Reliability

Accomplishments to date:

Developed a laboratory system for wheel inspection which includes PC controlled scanning, data acquisition, processing, and a neural network classifier.

Modified the system hardware and software for integration with the commercial wheel inpection system at NWA.

Obtained initial results of classification of engine fan disk inspection signals

Motivation:

* Assist Operator in Signal Interpretation
* Minimize Operator Fatigue
* Improve Consistency of Response
* Exception Handling
* Increase Accuracy, Speed and Reliability of Inspection
* Reduce Costs

Why Neural Networks ?

- These networks offer superior classification performance relative to existing algorithms

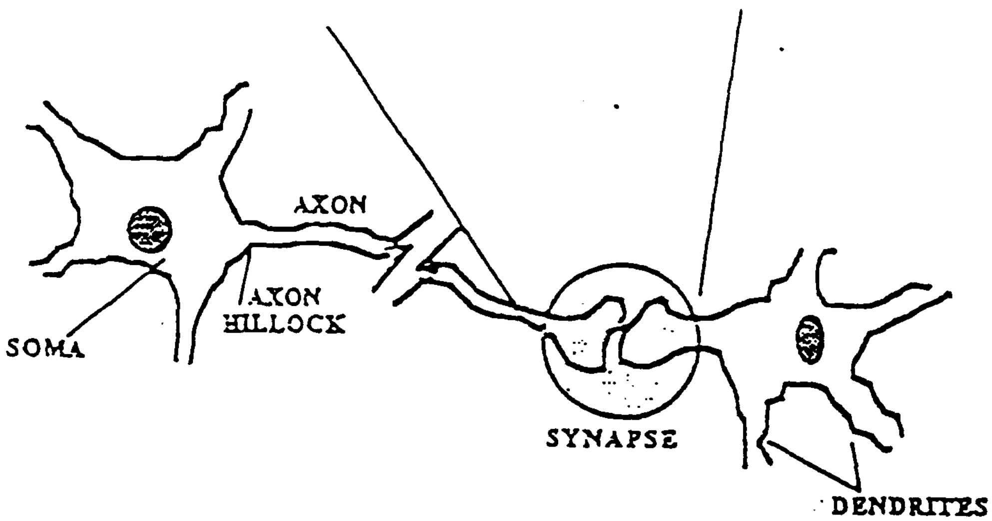
  - Robust in presence of noise
  - Reduced computational effort - can be implemented on PCs
  - No a priori information
  - Real time classification possible
  - Computational burden is independent of number of classes

Three basic features of a Neural Network

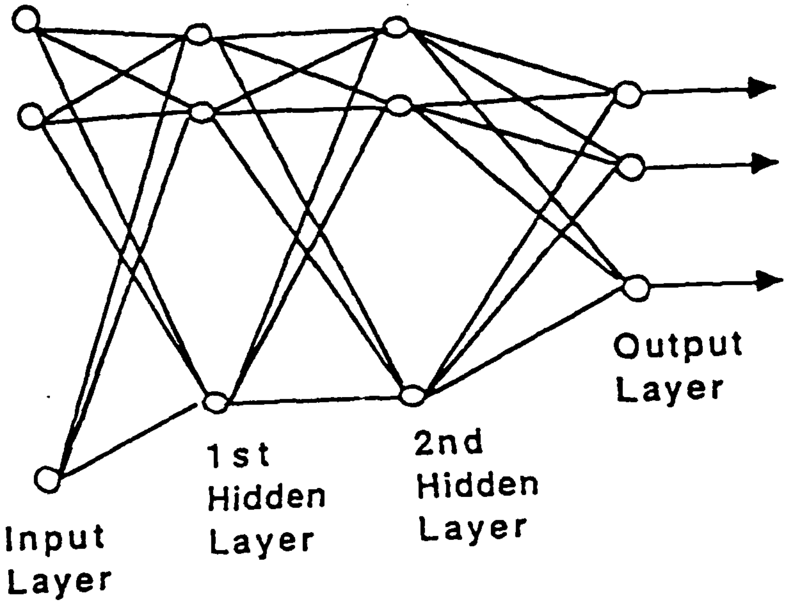
1. Large number of simple processing elements (neurons)

2. Dense interconnection between the neurons (dendrites and axons)

3. Functionality of the network determined by the interconnection weights (synaptic strength)



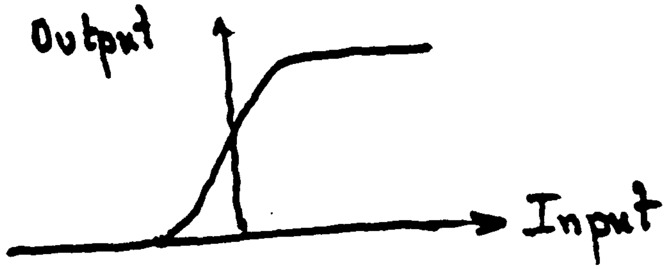
Multilayer Perceptron



Each node computes

1) the linear weighted sum $y'_i = \sum_{j=i}^{N} W_{ji} X_j$

2) the nonlinear function $y_i = f(y'_i)$



$$y_i = \frac{1}{1 + \exp(-\alpha\, y'_i)}$$

Neural Network Design

Training Phase -

Present data from known defect classes

Validation Phase -

Evaluate performance of network on data not presented during training

Training Algorithm:

* Backward propagation

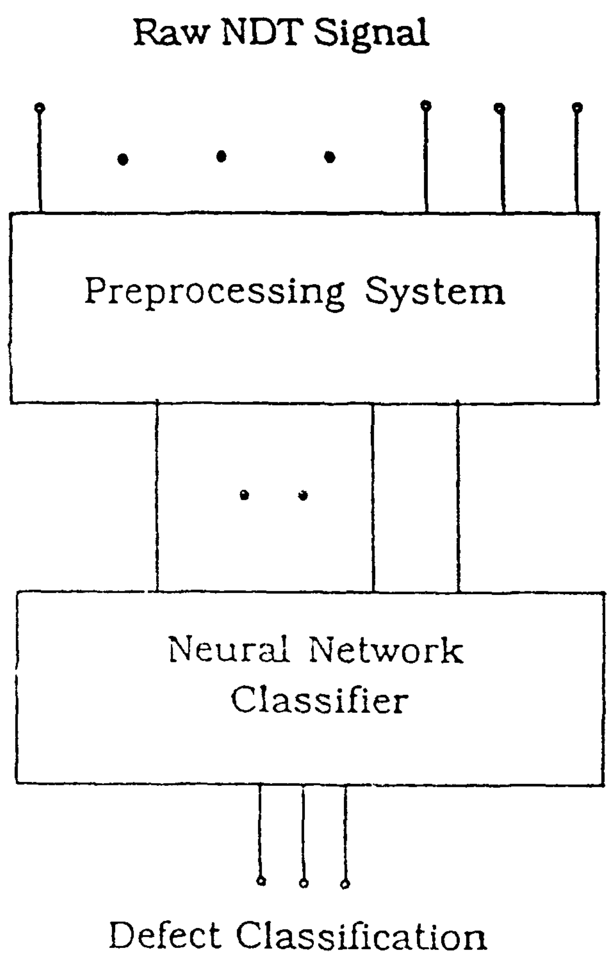
    * Present training input $\mathbf{x}$ and desired output $\mathbf{d}$

    * Calculate network output $\mathbf{y}$

    * Determine Error $E = \frac{1}{2} |\mathbf{y} - \mathbf{d}|^2$

    * Adjust interconnection weights to minimize E

The Overall Classification Scheme



System Block Diagram

The objectives of the preprocessor are two -fold :

1. Data compression

2. Invariance of the net under temporal shifts

Preprocessing Techniques

- Spectral Coefficients
- Discrete Cosine Transform
- Envelop Sampling
- Spectral Windowing
- Wavelet Transform

Applications

Wheel Inspection

Signal Processing
Classification
Sizing

Performance Measure

Fan disk Inspection

Classification

Desired Features

Airlines

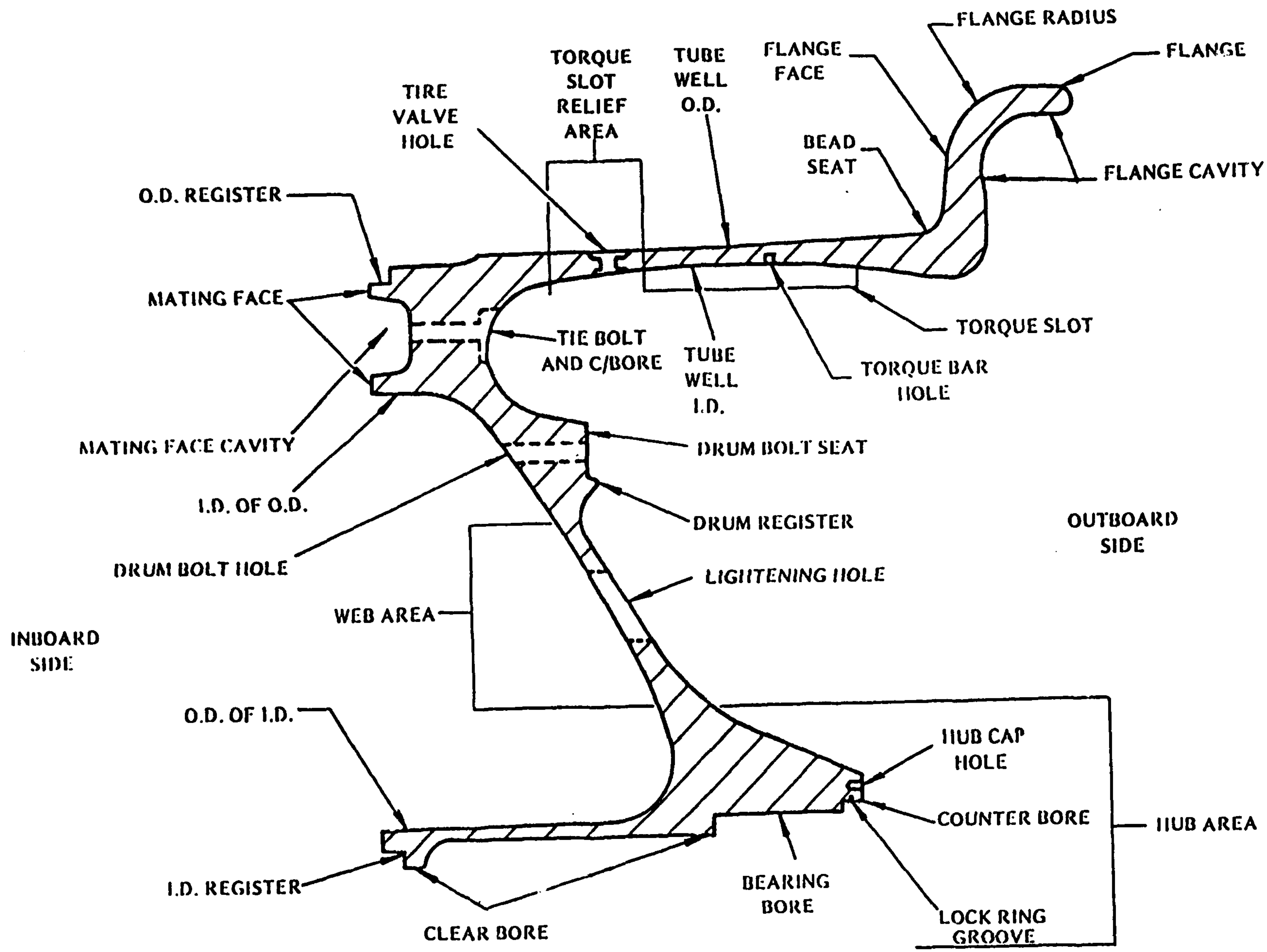
Surface Cracks
Subsurface Cracks
Corrosion

Wheel Manufacturers

Casting Inclusions Vs Fatigue Cracks
Surface Cracks - Sizing

General

Low Cost
Minimal Changes to Existing System



NOMENCLATURE – WHEEL HALF

ANDEC WHEEL TESTING SYSTEM

NWA Wheel Shop

Wheel Type DC-9

Test Date: Fri Dec 20 1991
Test Time: 14:12:31

20 dB gain

S/N ______________ Insp. ______________

16K

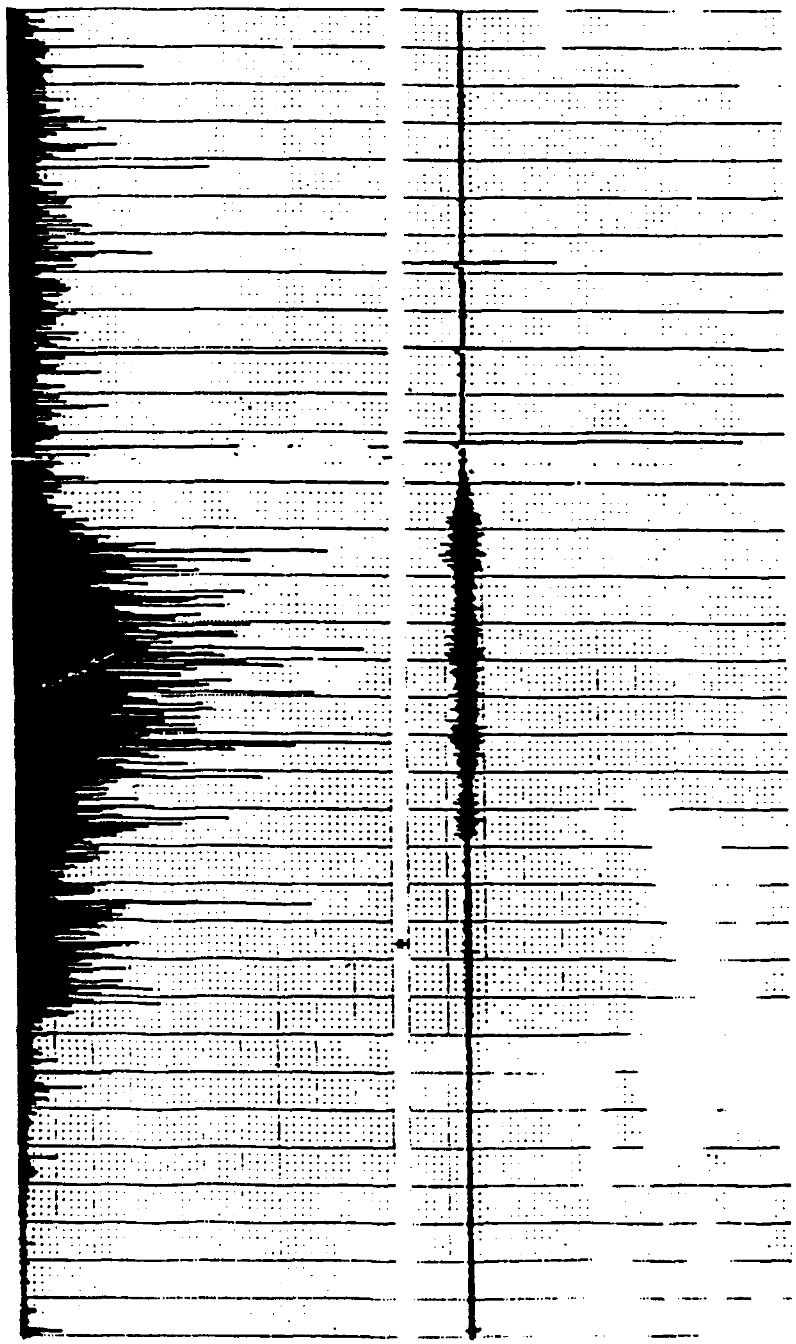
Low Frequency
Subsurface Defects

Y Component

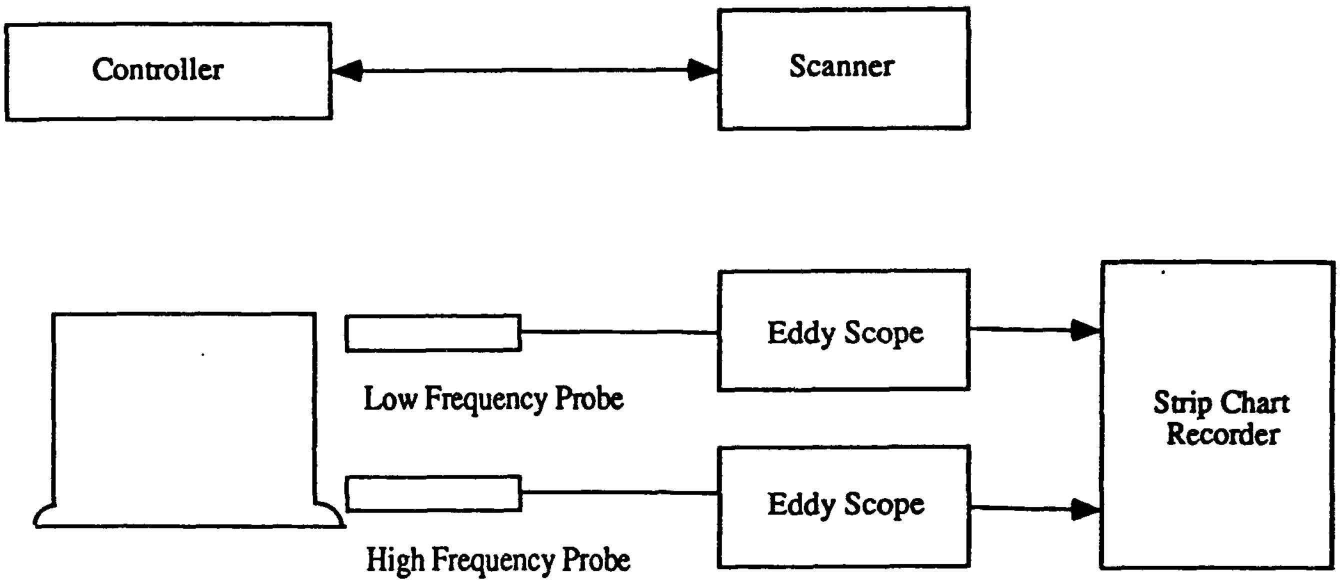
67K

High Frequency
Surface Defects

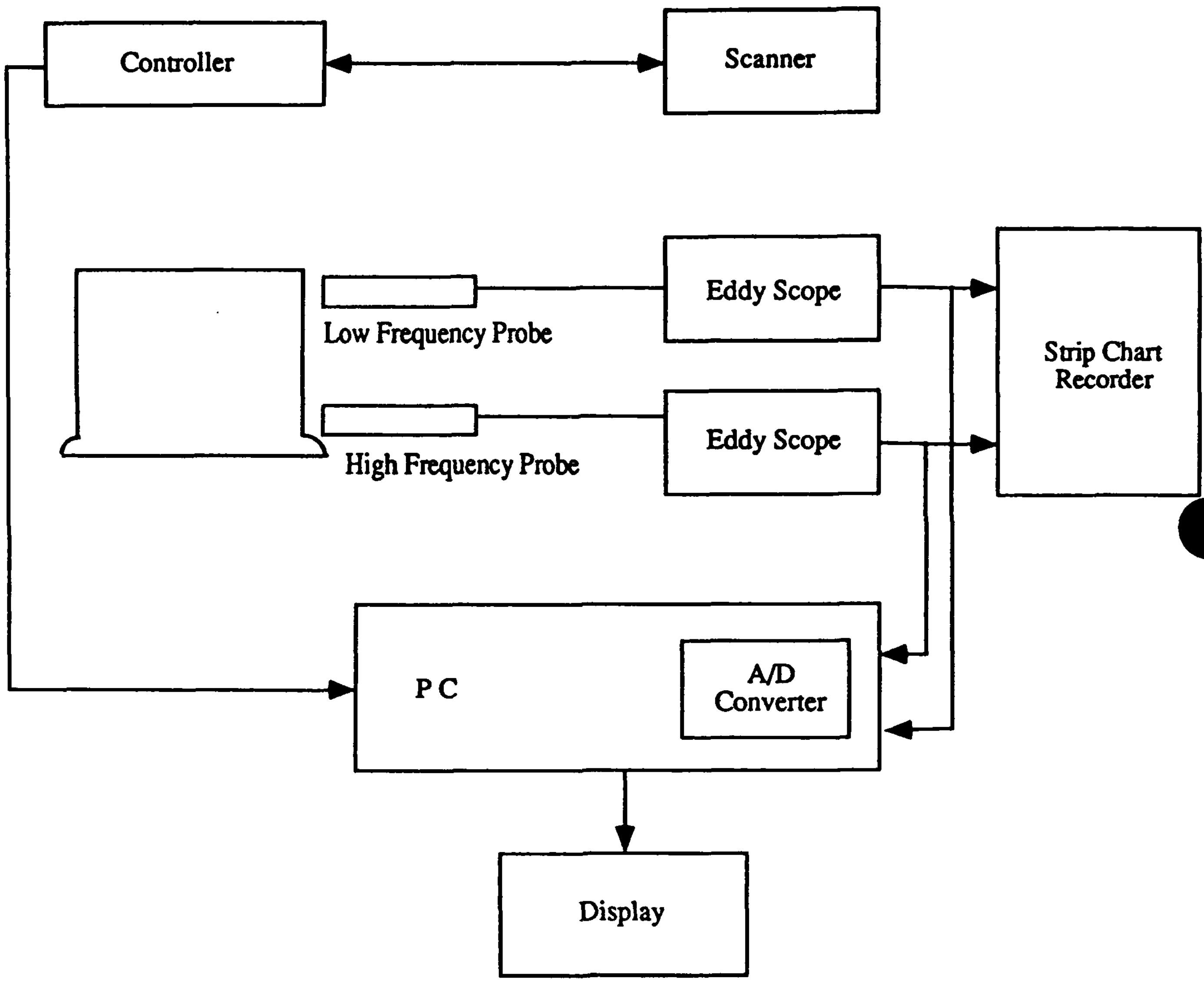
Y Component



Typical Wheel Inspection System



Modified Wheel Inspection System



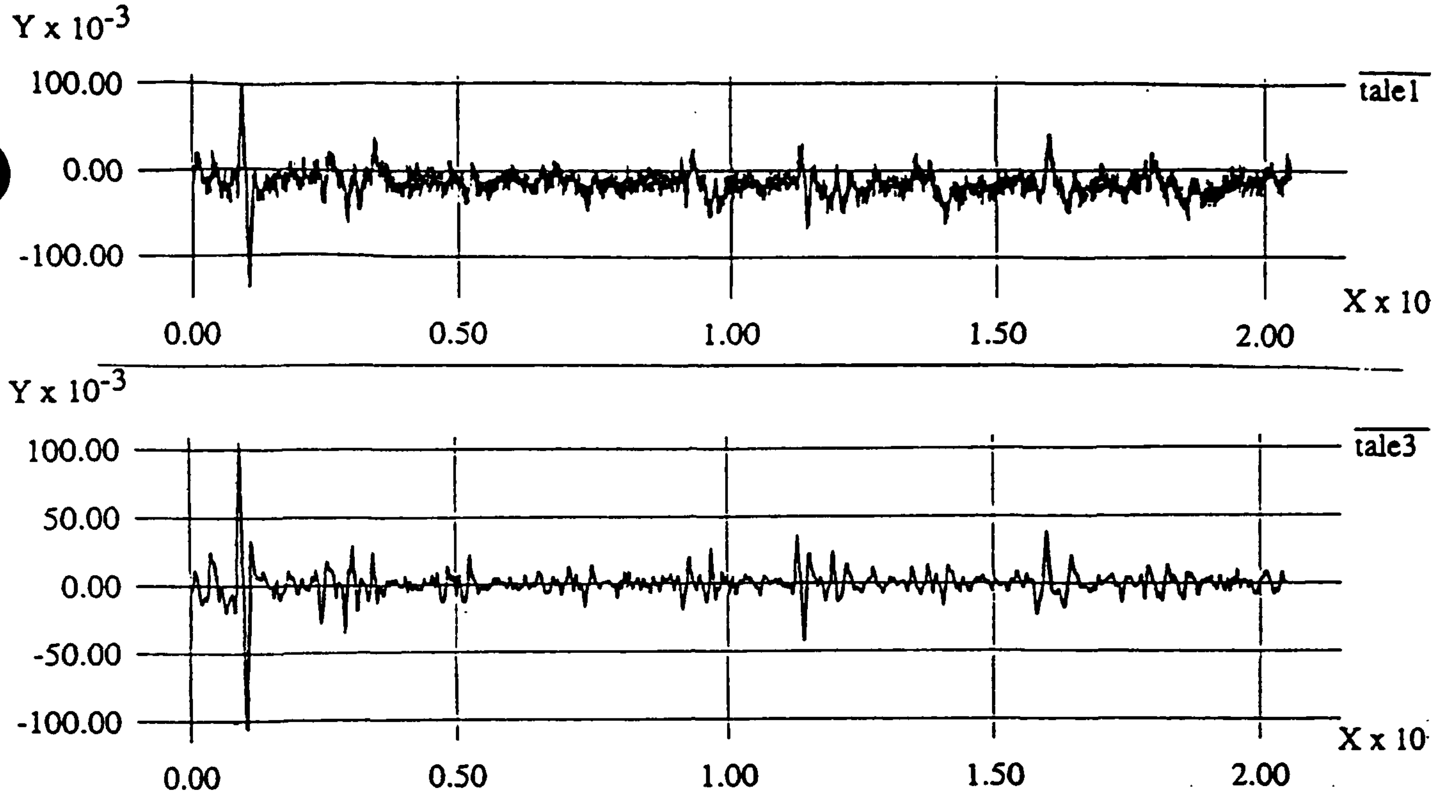


Figure 12a. Raw and Processed waveforms from the Horizontal component

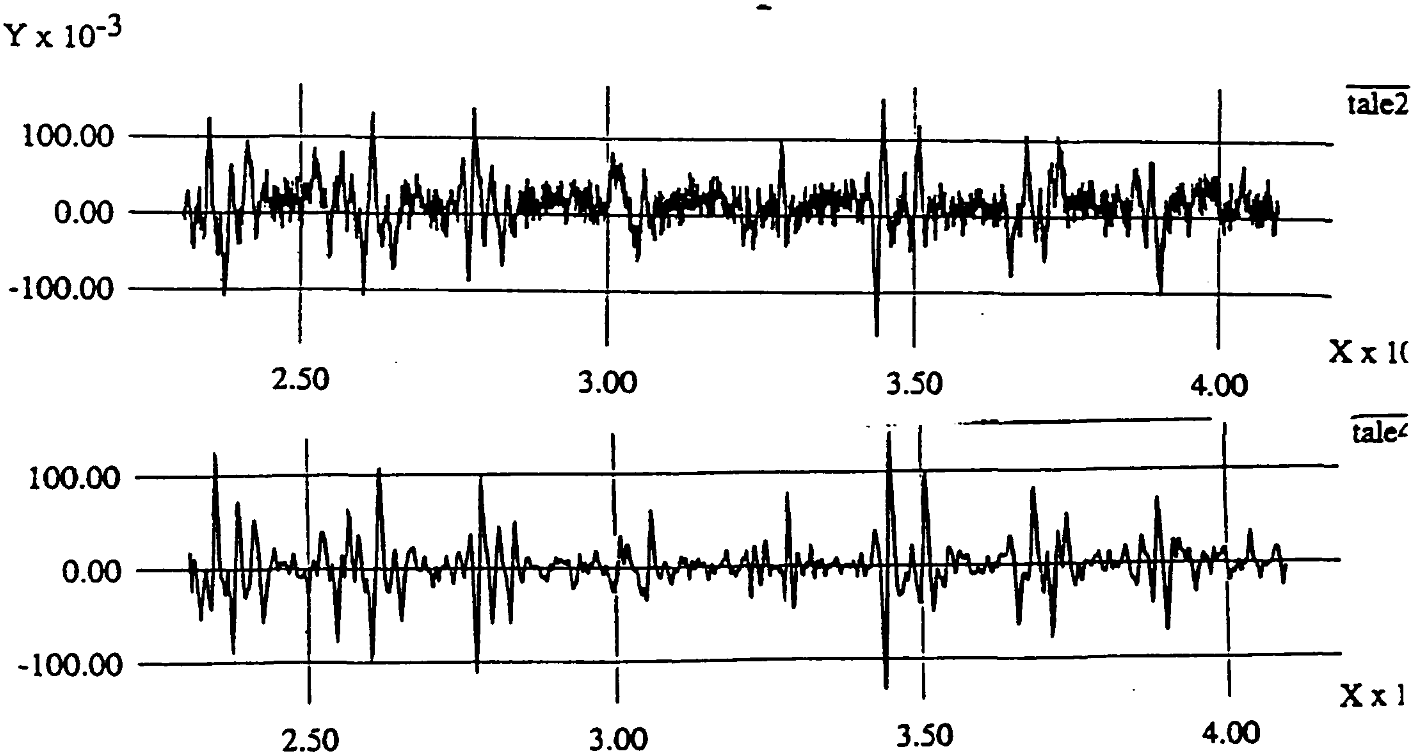


Figure12b. Raw and Processed waveforms from the Vertical component
(Low Frequency - 1 KHz)

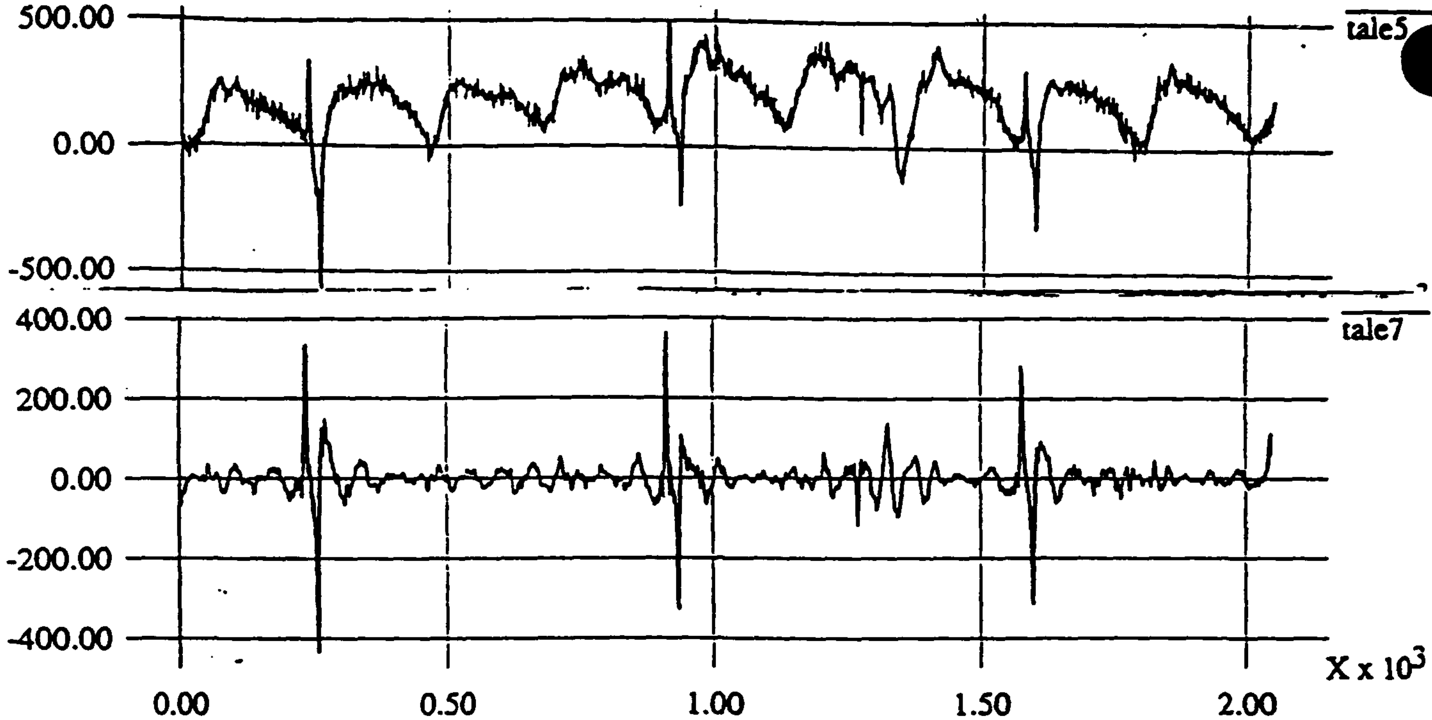


Figure 13a. Raw and Processed waveforms from the Horizontal component

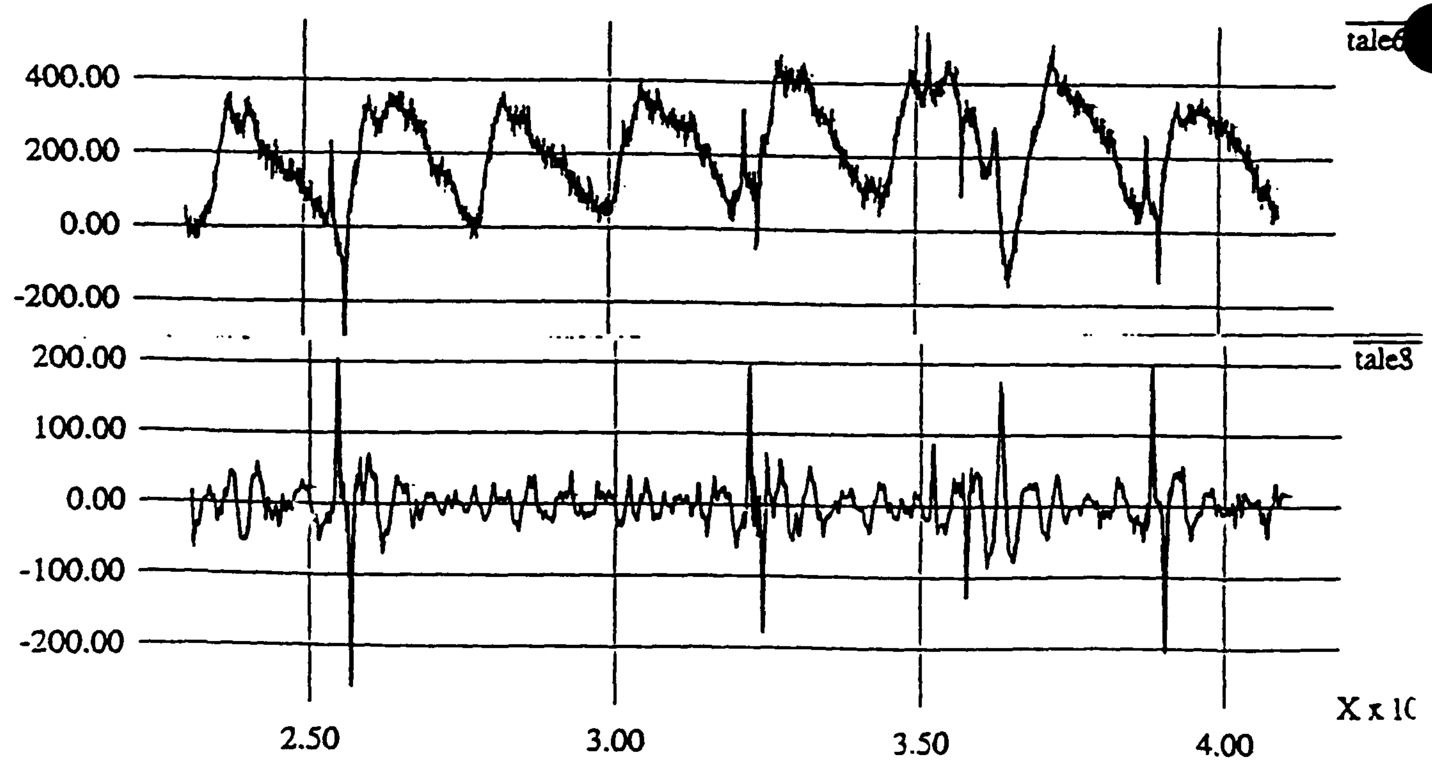


Figure 13b. Raw and Processed waveforms from the Vertical component
(High frequency - 66 KHz)

Classification Results using Wheel Inspection Data from NWA

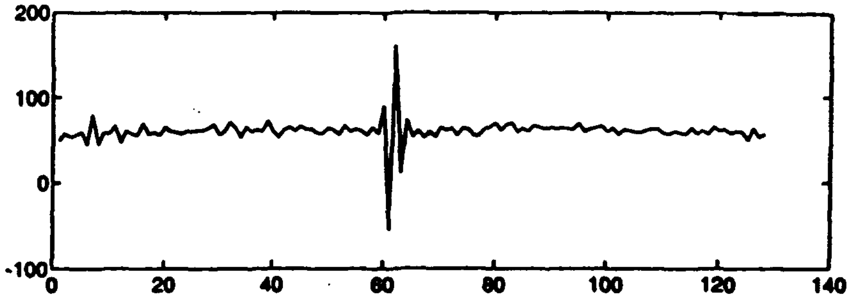
Total Number of Signals - 78

Number of Signals in the Training Set - 40

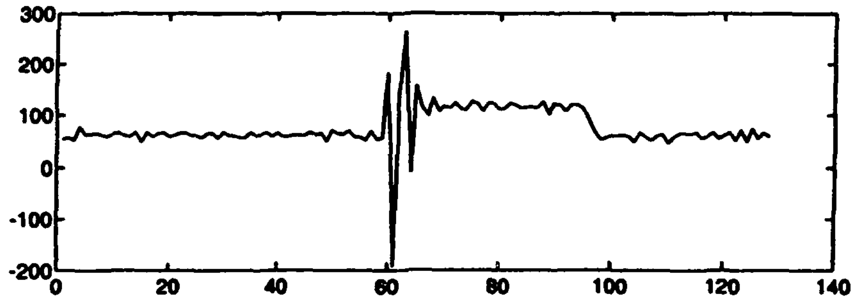
Number of Signals in the Testing Set - 78

Type of Signal	Total #	Number in Training set	# Signals classified Correctly
EDM Notch	5	3	5
Crack	38	16	38
Bead Seat Impressions	9	5	9
Double Crack	10	6	10
Manufactured Hole	16	10	16

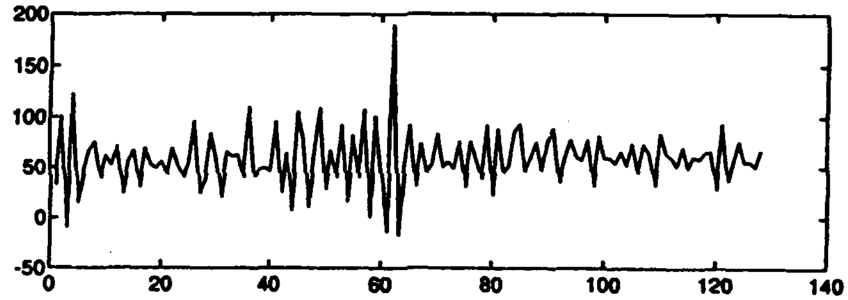
TYPICAL SIGNALS



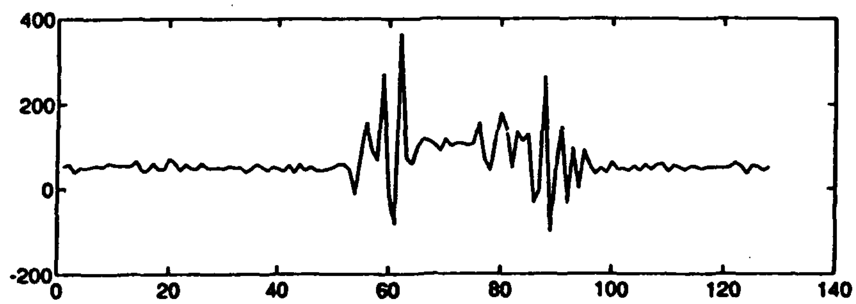
EDM Notch



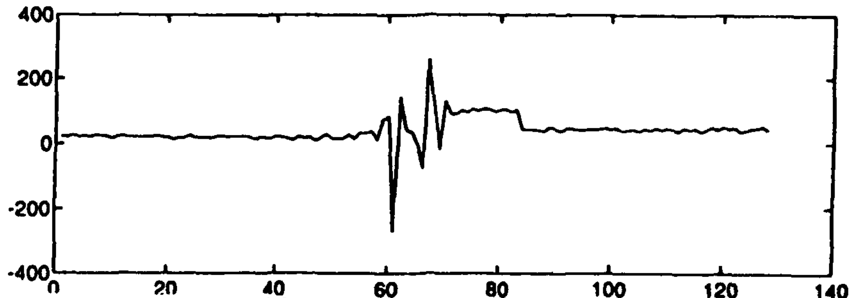
Crack



Bead Seat Impression



Double Crack

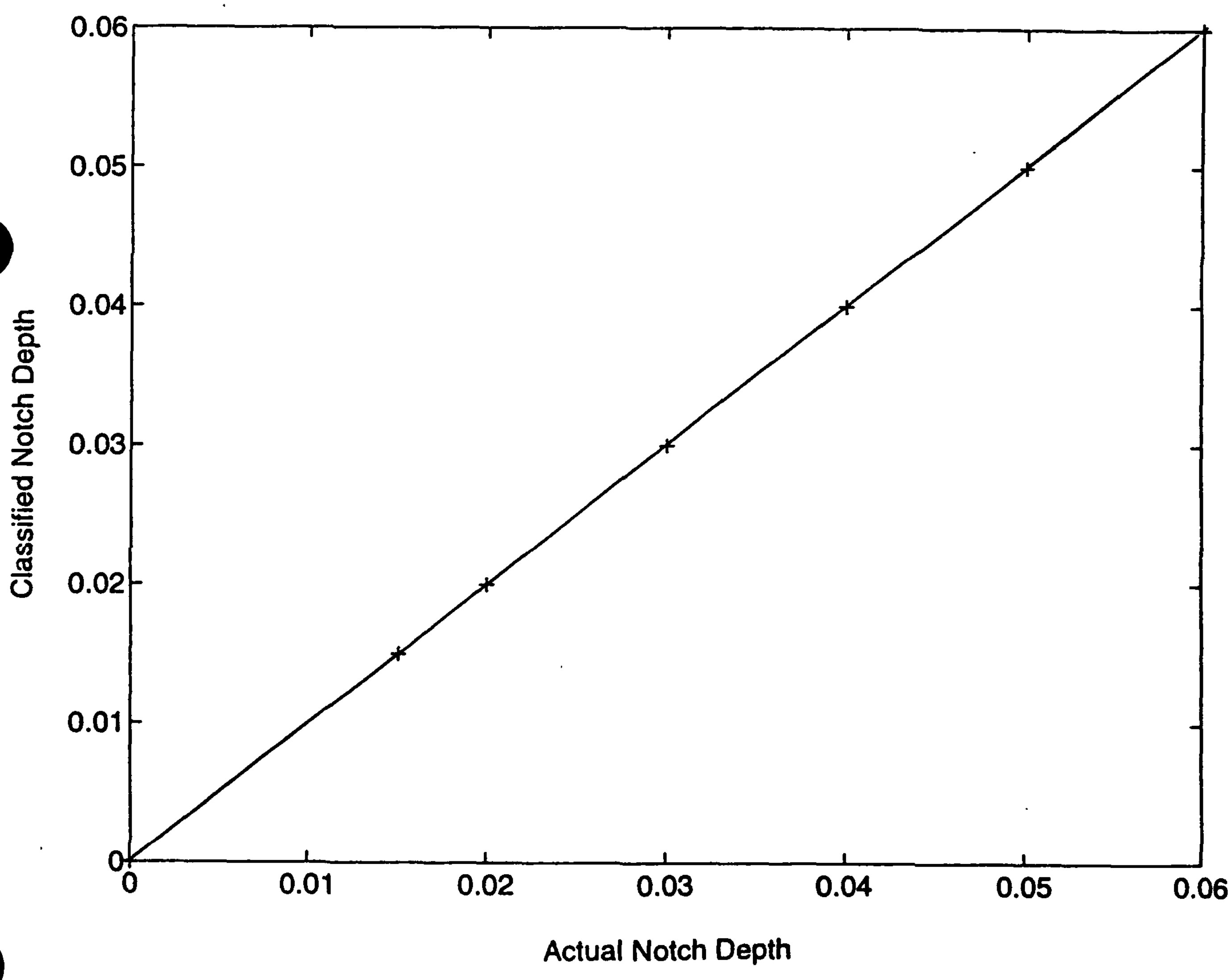


Manufactured Hole

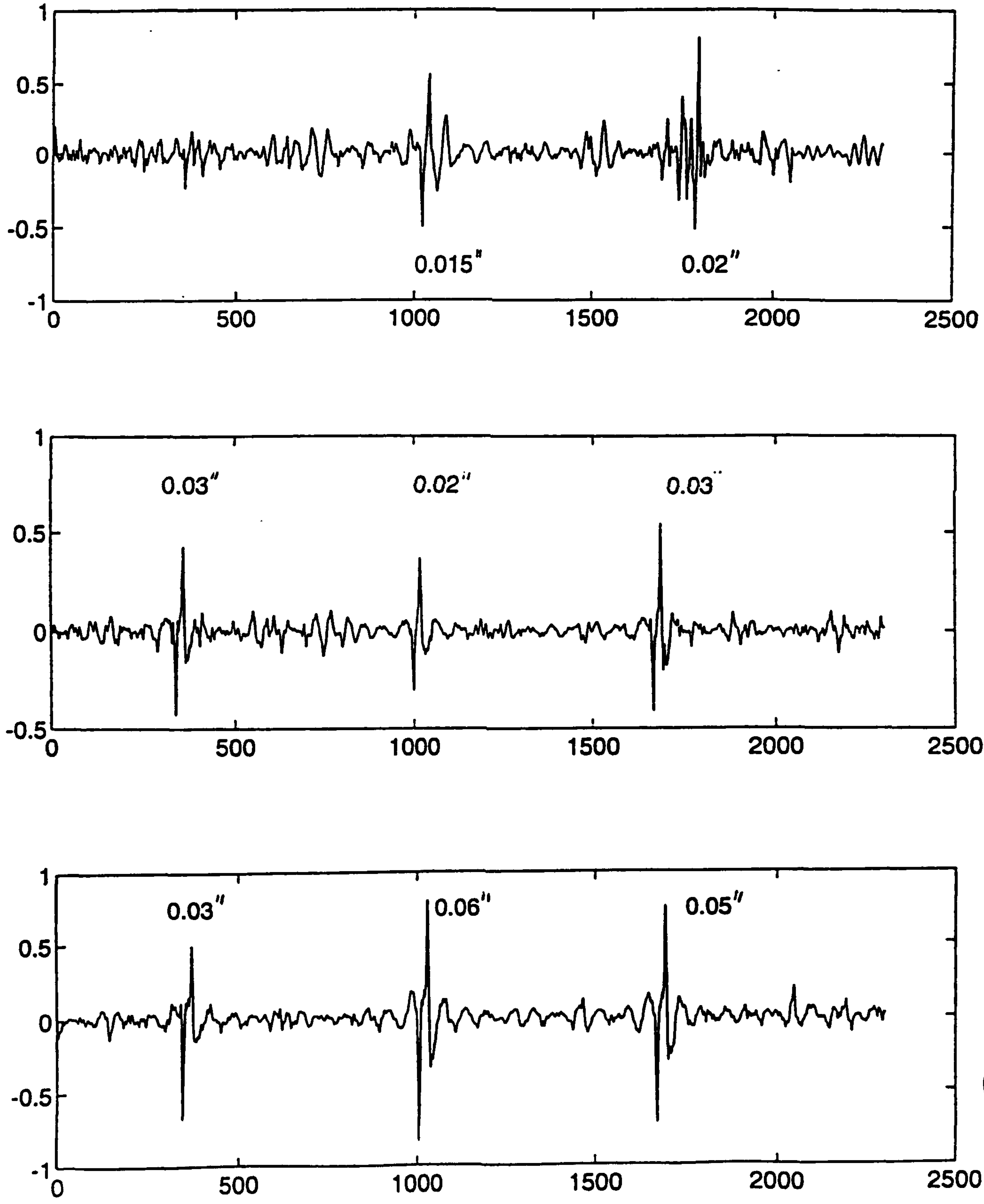
Sizing Results using RBF Networks

Data: EC Signals from O.D EDM Notches (NEXT PAGE)

Depth: 0.01", 0.015", 0.02", 0.03", 0.05", 0.06"



Eddy Current Scans of O.D Notches on the Boeing 747 Aircraft Wheel



Neural Network for Classification of Aircraft Wheel Inspection Data

Data Description:

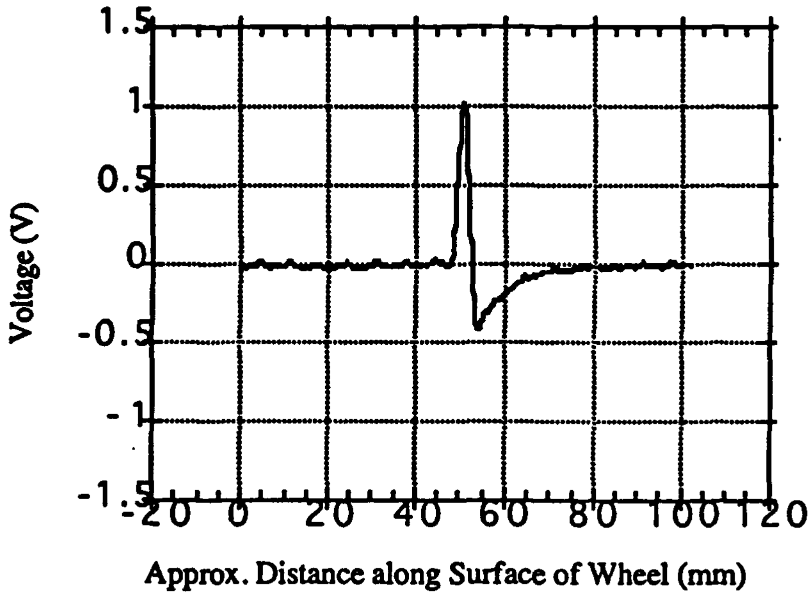
Signals acquired from wheels of various aircraft at United Airlines O'Hare facility, using AIT-MPC EL4 eddy current (high frequency) wheel scanning system.

Total number of Signals	-	**57**
Number of Signals in the Training set	-	**28**
Number of Signals in the Testing set	-	**29**

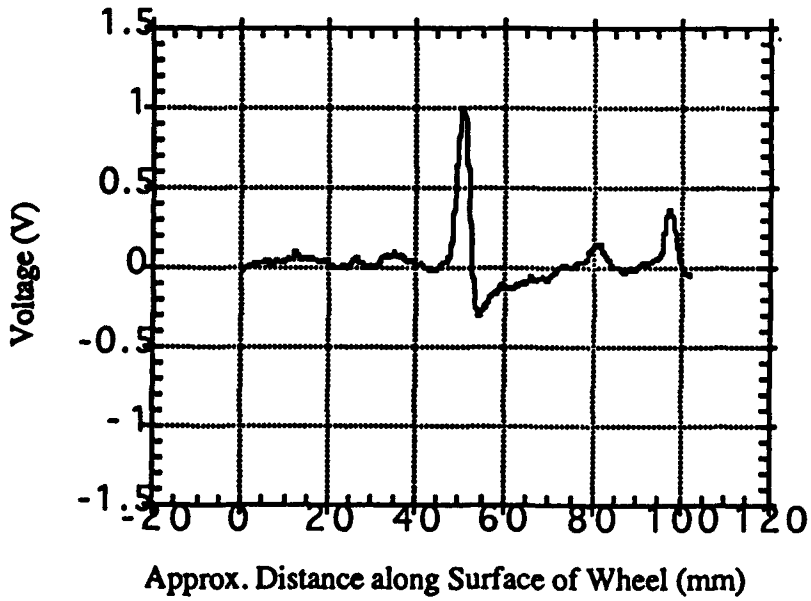
Defect Classes	# Signals in Training Set	# Signals in Testing Set	# Signals Classified Correctly
EDM Notch	6	8	7
Corrosion	9	6	6
Crack	8	7	5
Paint	6	7	7

TYPICAL SIGNALS FROM AIT WHEEL INSPECTION SYSTEM

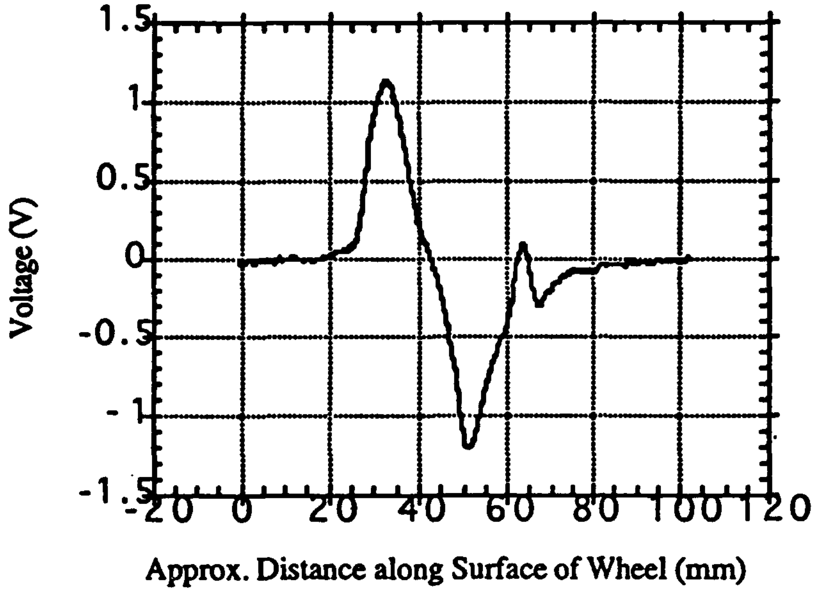
Signal from Calibration Flaw



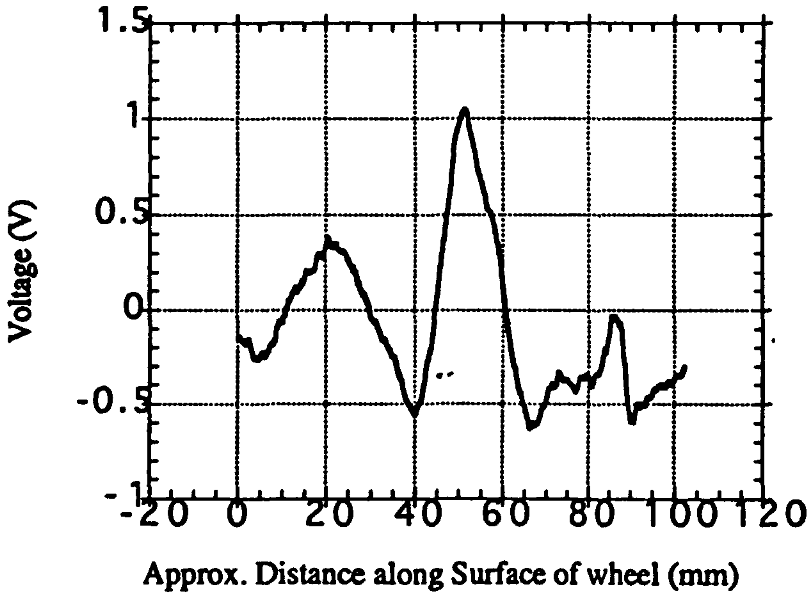
Signal from Deep Corrosion



Signal from Long Hairline Crack



Signal from a Long Ragged Crack



SYSTEM PERFORMANCE EVALUATION

i) Alarm Threshold Determination

- We must set an **alarm threshold**, Θ_{alarm}, to signify a flaw

- How to do it?

NEURAL NETWORK OUTPUT	$> \Theta_{alarm}$	=>	FLAW
	OTHERWISE		NOISE

- Neural network performance seems to depend on our choice of Θ_{alarm}!

- Θ_{alarm} too high gives low POD

- Θ_{alarm} too low gives high false alarm rate

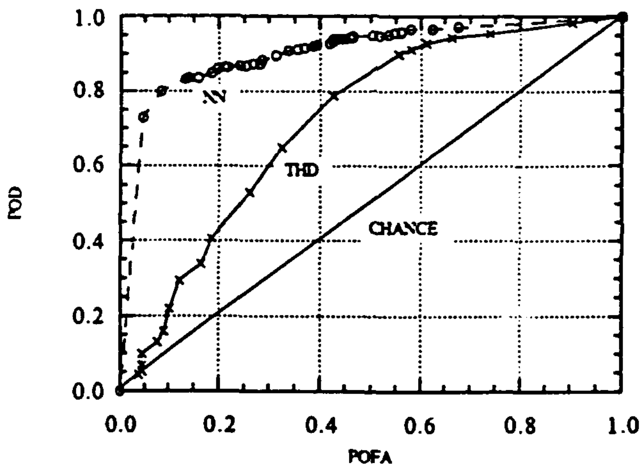
- How to objectively evaluate neural network performance when it seems to depend on an arbitrary Θ_{alarm}?

iv) System Performance Comparisons

Can compare all classifiers on ROC curves without the complicating question "What's the threshold?"

1) THD - use a threshold on signal magnitude, as is done now in practice

2) NN - process the signal with a neural network as we described, <u>then</u> use an alarm threshold



Relative Operating Characteristics of Neural Network (NN), Thresholder (THD), and Chance Signature Classification

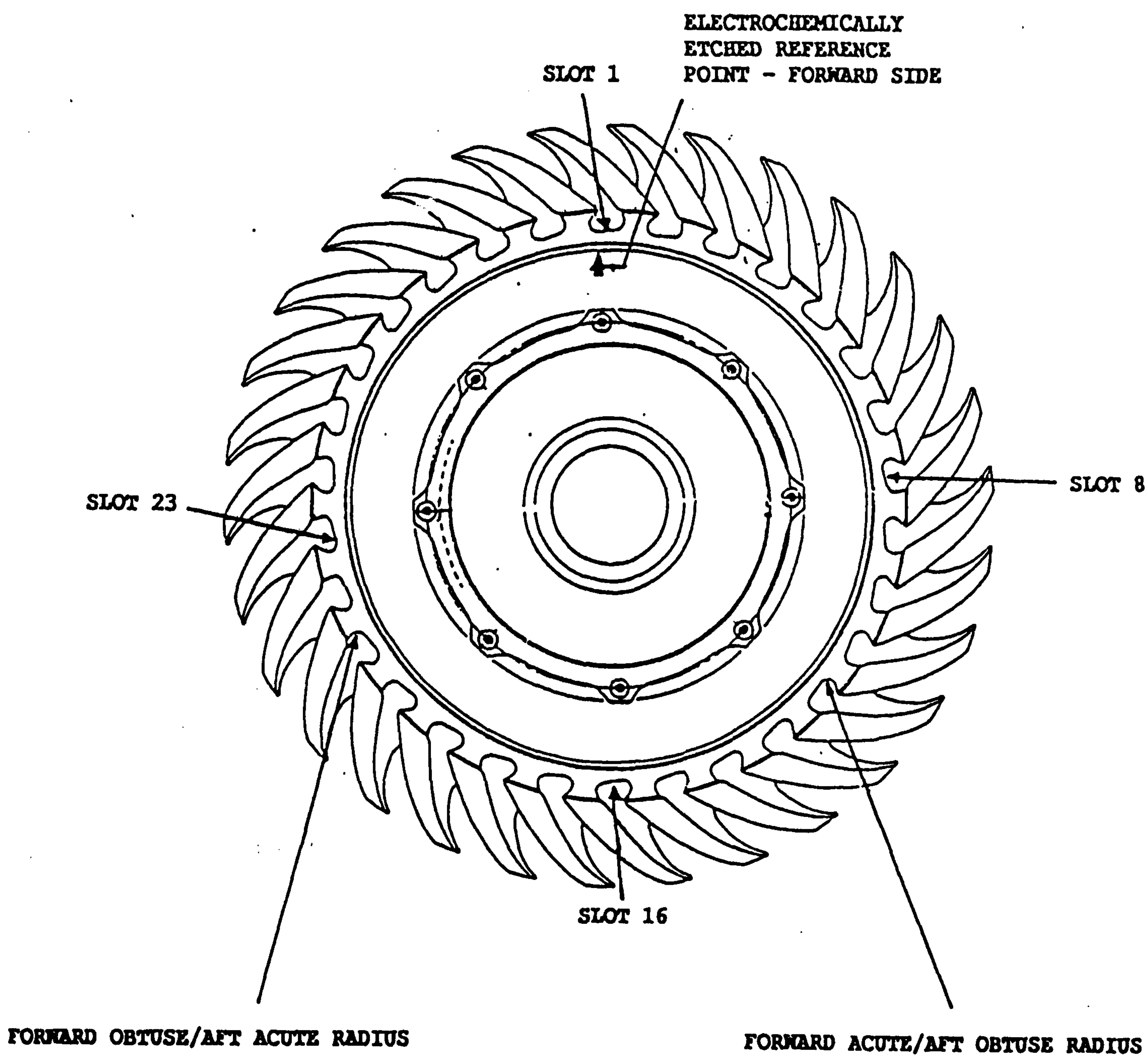
Fan Disk Inspection

- Volume of data per disk

30 Dove Tail Slots
Scanned twice using 3 test probes from two sides(aft & forward)

- Location of crack

Cracks occur only near acute edge of slot - crack indication is completely obscured by edge effect

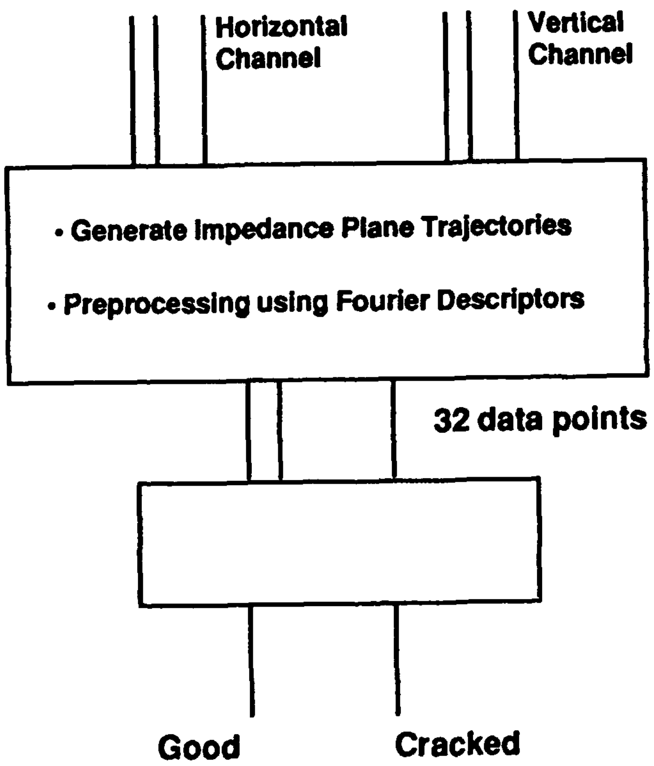

ELECTROCHEMICALLY
ETCHED REFERENCE
POINT - FORWARD SIDE
SLOT 1
SLOT 8
SLOT 23
SLOT 16
FORWARD OBTUSE/AFT ACUTE RADIUS
FORWARD ACUTE/AFT OBTUSE RADIUS

Neural Network Classification of Fan Disk Inspection Signals

Features of the system:

- Real time operation
- PC Based
- Low Cost
- Minimal operator training

Eddy Current Signals (1750 data points)



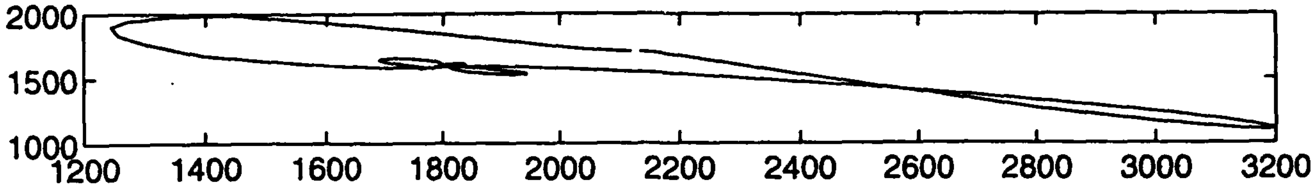
Initial Classfication Results
of
Fan Disk Inspection Signals

Total number of signals: 126
Number of signals in Training Set: 10
Number of signals in Testing Set: 116

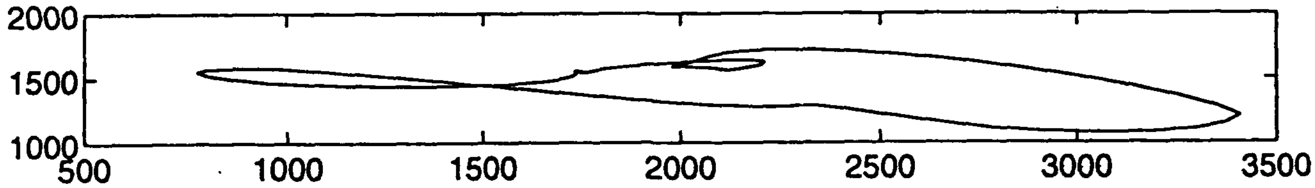
Defect Class	#signals in Training set	#signals in Testing set	# correct classifications
Good	5	90	84
Cracked	5	36	31
Potentially Cracked			11

FAN DISK INSPECTION SIGNALS

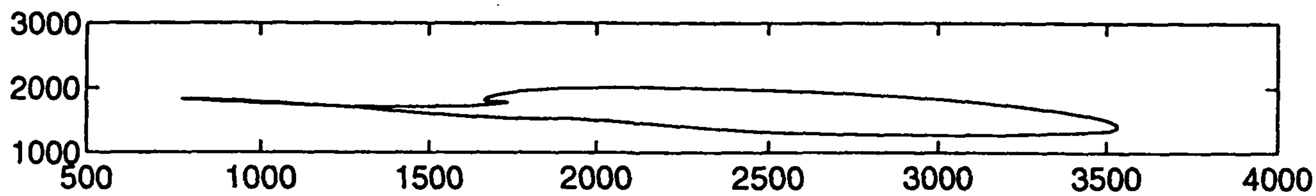
TYPICAL GOOD SIGNAL

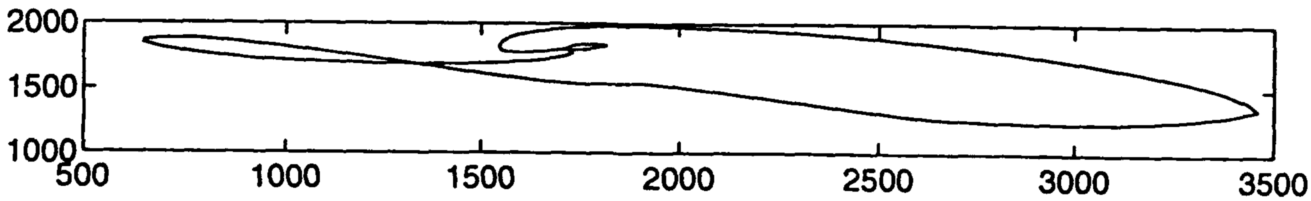


TYPICAL BAD SIGNAL



POTENTIALLY CRACKED SIGNALS





Reliability
RPI 205

FAA Center for Aviation Systems Reliability

Task: NDI Reliability

Future Directions:

Establish beta site at NWA for user evaluation of the wheel inspection system software and hardware

Evaluate feature extraction schemes for on line classification of fan disk inspection signals

Other Applications

Detection of fatigue cracks emanating from fastener holes in fuselage skin panel - in the skin and finger doublers - using high frequency EC sliding probes.

FAAREV ISU 4-94

Automation and Robotics
RPI 200

FAA Center for Aviation Systems Reliability

Project:	NDI Automation and Robotics
Task:	Image Processing for Radiographic Inspection
Principal Investigator:	R. Wallingford
FAA Sponsor:	F. Sobek
FAA Technical Monitor:	D. Galella
Industrial Contacts:	Gerald Doetkott (Northwest Airlines) Frank Smith (Northwest Airlines) Dale Mullinax (Northwest Airlines) Roy Bailey (Delta Airlines)

Automation and Robotics
RPI 200

FAA Center for Aviation Systems Reliability

Task: Image Processing for Real-Time Radiographic Inspection

Objectives:

- Develop a low-cost PC based real-time image processor
- Improve inspection reliability in real-time x-ray NDI
- Test and evaluate the image processor in airline(s) existing real-time inspection system

Deliverables:

- Real-time image processor hardware and software
- Video demonstrating successful inspection improvement
- Technical Documentation
- User manual

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection

Current Problems with Real-Time X-ray NDI:

- Lack of sensitivity
- Low contrast critical flaws
- Noisy
- Lack of quantitative analysis capability
- Lack of archival /printing capability

Airline Requirements for Processing System:

- Image processing performed in real-time or near real-time
- Significant detectability benefits
- Low cost
- Integrable with existing real-time inspection systems
- Easy to operate

Automation and Robotics
RPI 200

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection

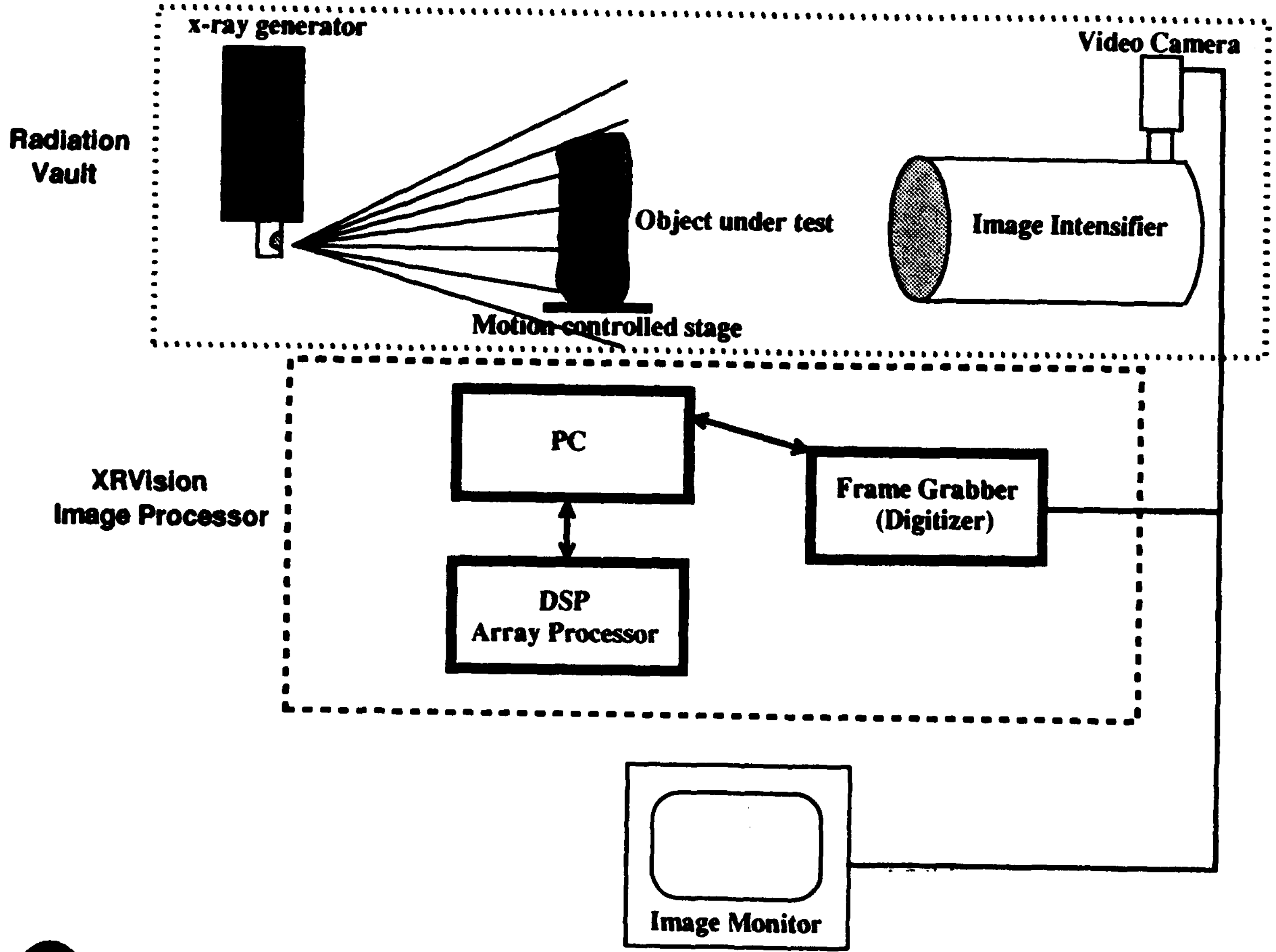
Accomplishments This Year:

- Developed and implemented real-time processor, called XRVision, for dramatically improving real-time x-ray inspection reliability
- Implemented on a low-cost PC-based platform for add-on to existing real-time inspection systems
- Successfully demonstrated the power of real-time processing on variety of inspection samples
- Established contacts with inspection personnel at Northwest Airlines and arranged a beta-test in the next several months, depending on airline's schedule

Automation and Robotics
RPI 200

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection



Inspection System

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection

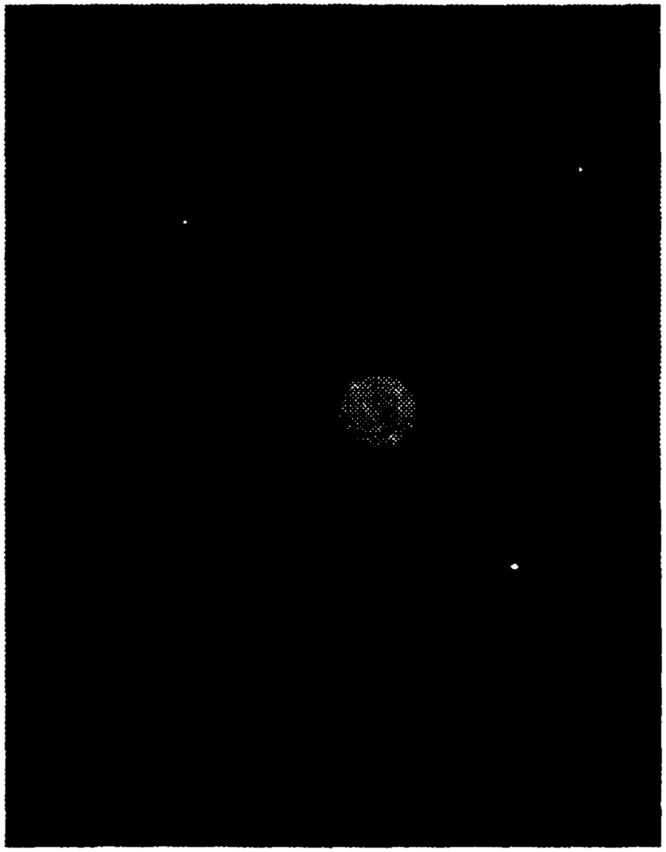
System Features:

- Powerful, yet fast processing strategy
  - Real-time noise reduction
  - Improved sensitivity via image calibration
  - Improved range of data (16 bit capability)
  - Improved contrast
- Standard image analysis and archival tools
- Implemented using low-cost hardware
- Easy integration with existing inspection systems
- User-friendly interface

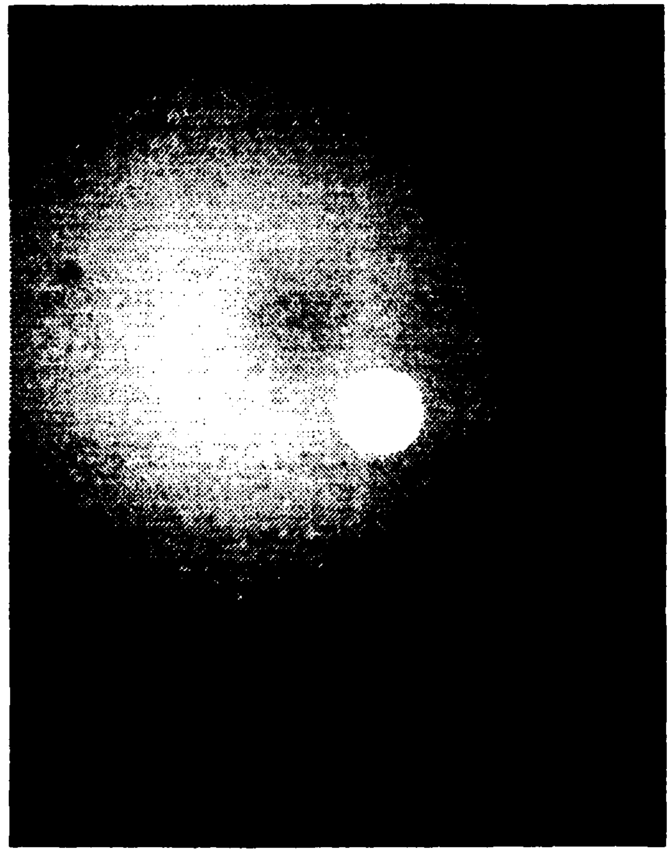
Automation and Robotics
RPI 200

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection



Unprocessed image

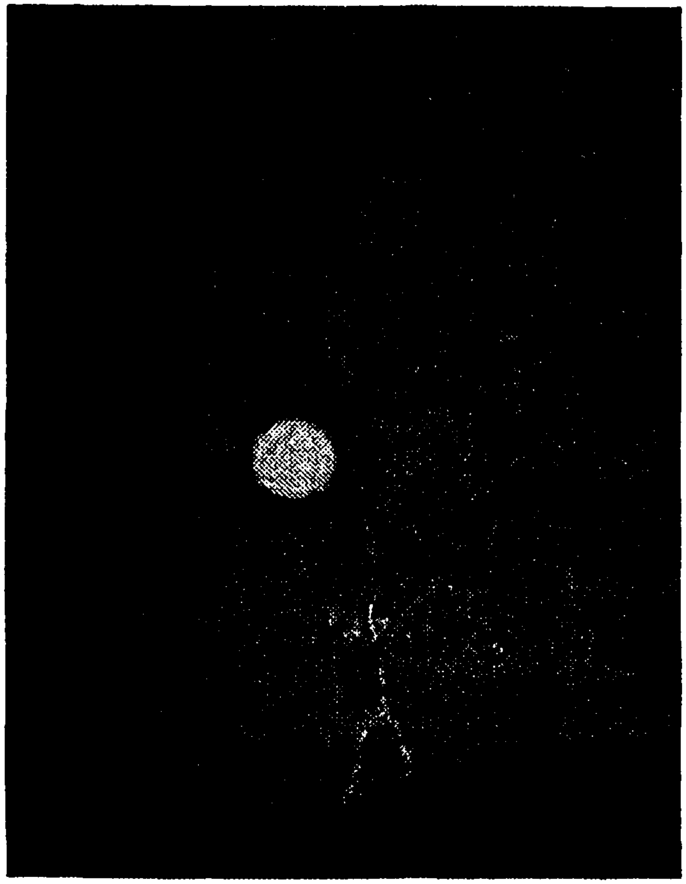


Conventional processing

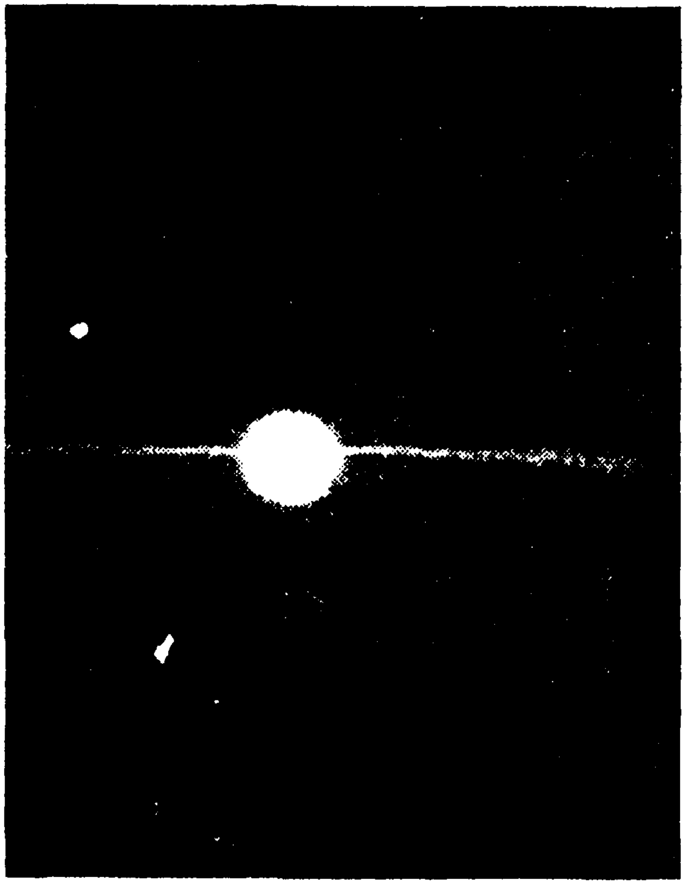
Automation and Robotics
RPI 200

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection



Unprocessed Image

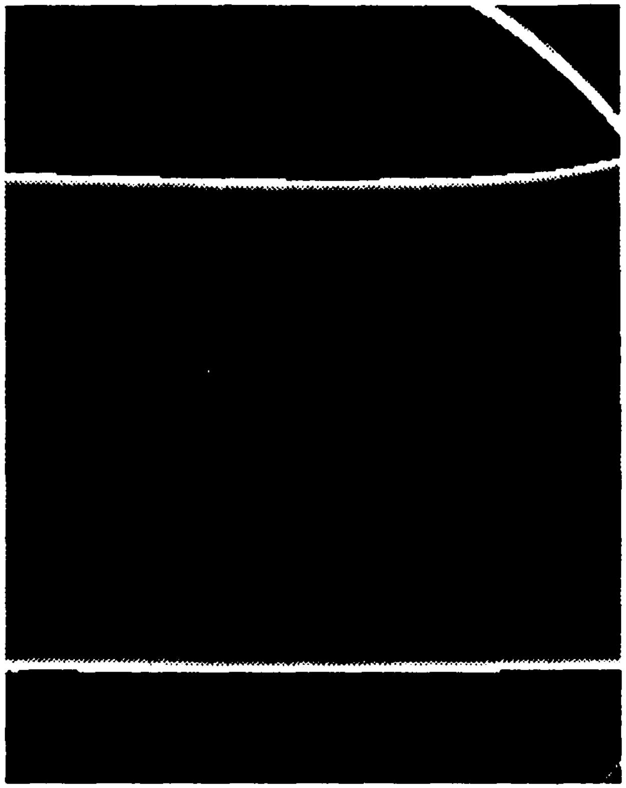


XRVision Processor

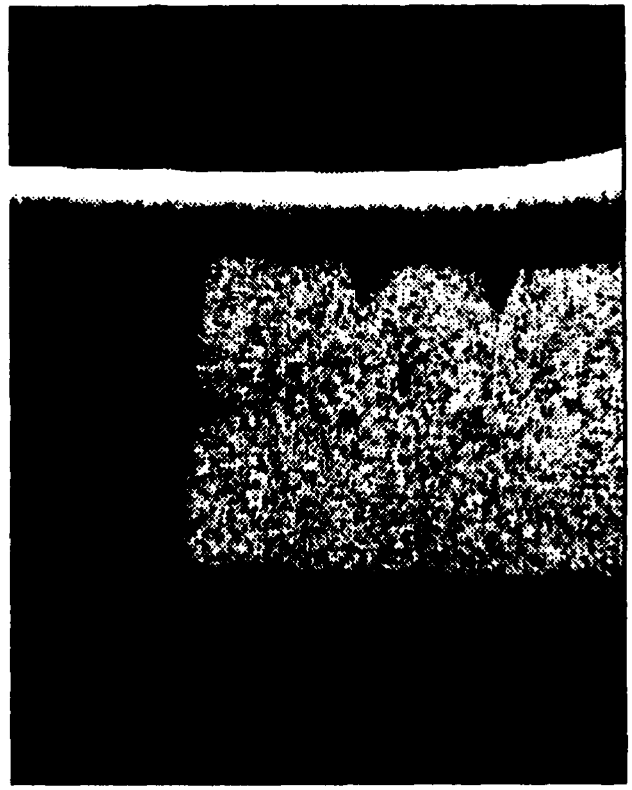
Automation and Robotics
RPI 200

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection



Conventional capability:
~4% thickness sensitivity



XRVision processing:
< 1% thickness sensitivity

Illustration of Sensitivity Improvement Through Processing

Processing Techniques:

- Image Calibration
  - Corrects image intensifier response
  - Corrects camera response
  - Analytical or subtraction method
  - Improvement over "frame-shift" method

- Contrast Manipulation
  - Utilizes hardware lookup table circuitry
  - Real-time display
  - Increases POD for low-contrast critical flaws

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection

Processing Techniques:

- Integration
  - Extends image data from 8 bits to 16 bits
  - Flexible offset and divide for image display
  - Offers maximum sensitivity

- Recursive, exponential, weighted, moving average filter
  - Removes noise
  - Yields real-time update (fast)
  - Weighting factor tradeoff (noise removal vs. motion blur)

FAA Center for Aviation Systems Reliability

Task: Image Processing for Radiographic Inspection

Future Plans:

- Perform beta testing at Northwest Airline's real-time x-ray inspection facility
- Perform modifications on processing techniques and user interface based on beta evaluation
- Solicit other beta sites
- Implement generalized calibration procedure for inspection of complex geometries

THE PROCESS OF INNOVATION

- UNDERSTANDING HOW "TECHNOLOGICAL POSSIBILITIES" ARE GENERATED, DEVELOPED, INTRODUCED AND DIFFUSED IS OF INTEREST TO:

  - CARRIERS
  - SUPPLIERS
  - CUSTOMERS
  - THE FINANCIAL COMMUNITY
  - PUBLIC OFFICIALS
  - POLITICIANS
  - THE GENERAL PUBLIC

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April 1994

THE PROCESS OF INNOVATION (CONT'D)

- THE PROCESS OF INNOVATION HAS GENERALLY BEEN ILL-DEFINED
- BETTER APPRECIATION FOR THIS PROCESS AND GREATER UNDERSTANDING OF IT WILL PAY GREAT DIVIDENDS FOR ALL CONCERNED
- NOT ONLY THE CATALYSTS TO TECHNOLOGICAL CHANGE AND INNOVATION NEED TO BE IDENTIFIED AND UNDERSTOOD BUT THE BARRIERS AS WELL

WHAT ARE INVENTION & INNOVATION?

INVENTION...TO CONCEIVE...THE IDEA

INNOVATION...TO USE...THE PROCESS BY WHICH AN INVENTION OR IDEA IS TRANSLATED INTO A PRODUCT OR PROCESS AND BROUGHT INTO THE MARKETPLACE.

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INTANGIBLE TECHNOLOGIES

TECHNOLOGY IS NOT MERELY HARDWARE

TECHNOLOGY INCLUDES THE WAYS THINGS ARE MADE OR DONE

- TECHNIQUES
- METHODS
- APPROACHES

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TECHNOLOGY:
ONE CLASSIFICATION SCHEME

PRODUCT-EMBODIED TECHNOLOGY

PROCESS TECHNOLOGY

MANAGEMENT TECHNOLOGY AND TECHNIQUE

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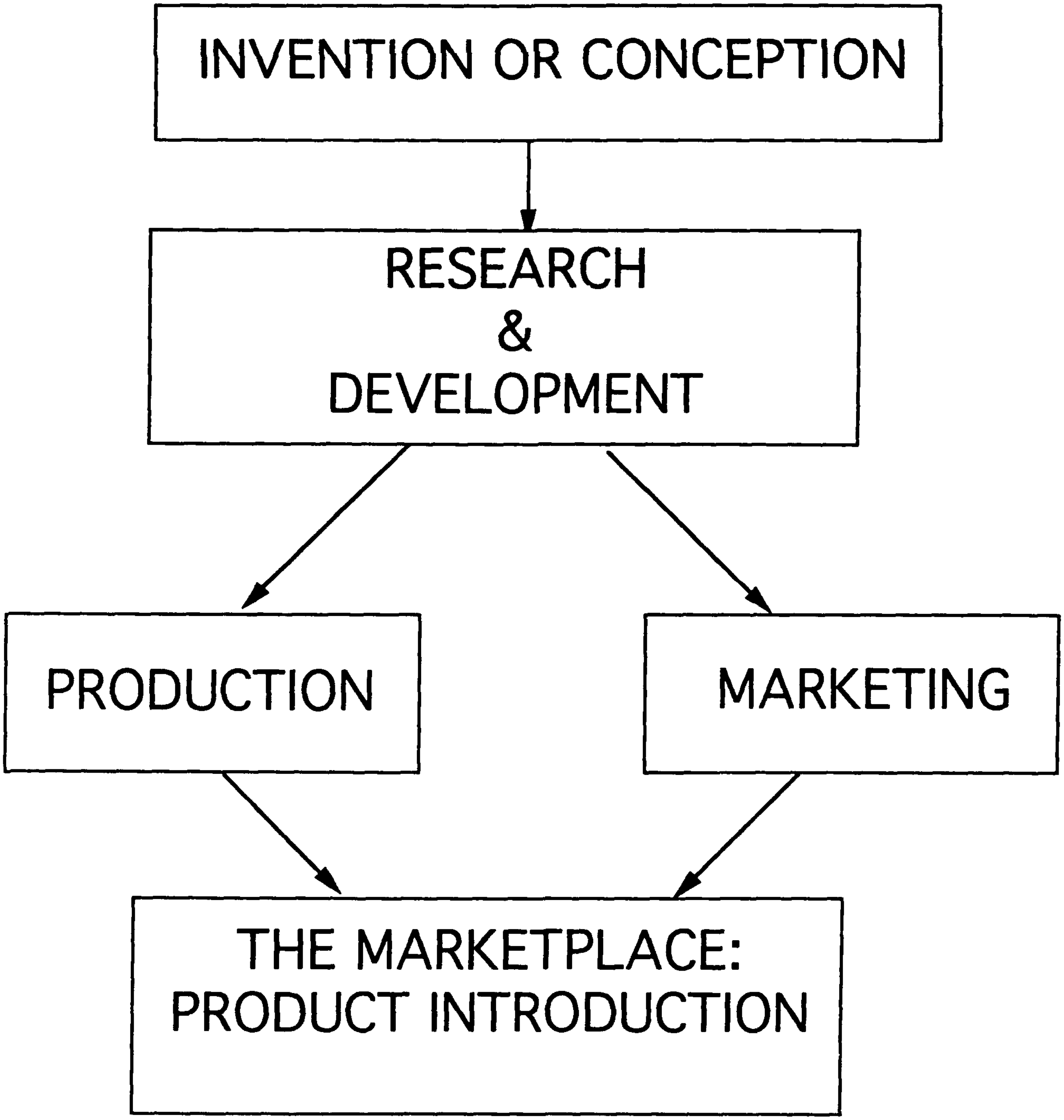
THE PROCESS OF INNOVATION IN SIMPLEST FORM



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THE GENESIS OF INNOVATION

- SUPPLY—PUSH
- DEMAND—PULL

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Updating the Certification of Aviation Maintenance Technicians (AMTs)

- Purpose and Objective
- Phases of Research
- Results of Phase I
- Progression into Phase II
- Constraints and Issues

Purpose and Objective

- Perform a Job Task Analysis of the Aviation Maintenance Technician

- Update the tasks an AMT performs
  - -Regulatory perspective
  - -FAR Part 65; Certification of Airman Other than Flight Crews
  - -FAR Part 147; Certification of AMT Schools

Purpose Clarified

- To influence the productivity of AMTs

  reduce industry costs for training

- To Provide the FAA with information needed in <u>GUIDING</u> the process of revising rules and regulations

- To provide students with an [illegible] opportunity to [illegible]

Phase I: Complete a Pilot JTA

- Cross-reference tasks originally included in Allen Study
- Sample of new tasks not in Allen Study (new technologies)
- Permit direct comoparison of tasks between Northwestern JTA and Allen Study

Phase I: Data Collection

- Three components:
  - -Survey (25% Sample)
  - -Interviews (Job Functions)
  - -Observations (As Applicable)

- Background, Documentation, Task and Specialty Service information is collected

Phase I: Site Coverage

- General aviation shops in Chicago
- Airline line maintenance facilities at O'Hare
- National study including overhaul and general aviation facilities

Questions For Analysis

- Identify a core set of tasks that continue to be important

- Identify a subset of tasks that appear to be obsolete (to be de-emphasized)

- Identify a subset of tasks associated with new technology (candidates for increasing emphasis.)

Additional Questions for Analysis

- Compare different segments of the industry
  In what repects are these different jobs
- Compare skilled AMTs with AMTs who are recent school graduates
- Can we define training as collaboration between two components: Schools plus on-the job?

Results of Phase I

- Survey approach works
  - -Clear instructions and rating scales
- Interviews need to be revised

Progression into Phase II

- Identification of Task List
  - -Aggregated to manageable level
- Establishment of Visit Committee
  - -Representatives from all aviation segments
  - -Assistance with project strategy and research visits
- Revision of Interview Schedule

Progression into Phase II

- Development of revised surveys
  - -Engine shop
  - -Airline line maintenance
  - -General aviation overhaul maintenance
- Assure proper survey sample
- Identify site strategies

Progression into Phase II Revising the Survey

- Eliminate redundancy in the individual task questions
- Can we manage with 3 rating scales rather than 6?
  - -Frequency
  - -Importance
  - -Industry Training
- Emphasize breadth of coverage: Limited Depth
  - -10 to 12 major job functions that "cover" the job
  - -8 to 10 tasks or subfunctions for each function
  - -target: 60 to 80 tasks total

Progression into Phase II Revising the interview

- **Significant Questions**
  - -Company expectations of newly hired AMTs.
  - -Company desires for improvements in the competence of newly hired AMTs.
  - -Company emphasis on indoctrination and supervision
  - -Continuing programs for on-the-job training
- **Coping with Technological change**
  - -How is this being managed?
  - -What plans exist for managing change in the future?

Constraints and Issues

- How rapidly can we finish?
- Strategy: Feed data into the relevant FAA Advisory committees?
- Skill Implications (i.e. Curriculum Implications): Should these be a primary responsibility of industry and the schools?
- How can one coordinate discussions of
  - -AMT certification with
  - -Curriculum Revision
- Need for experimental approaches using "Centers of Excellence"

Development of Education and Training Programs for Aviation Safety Inspectors

FAA Center for Aviation Systems Reliability

Lisa Brasche
Iowa State University
Ames, Iowa

FAA-CASR

Project 2 Education and Training
Task 6 FAA NDI Course Development

Objective: To develop an NDI course for FAA Airworthiness Inspectors which relates the performance of NDI to the ASI's job responsibilities

Approach:

Formation of FAA NDI Training Design Panel
Identify critical elements for course
Prepare students and instructor materials
Hold walkthrough
Prototype at FAA Training Academy
Deliver final course materials to FAA

FAA NDI Training Design Panel

Role: To establish course priorities and objectives, to provide technical content and to assist with development of course materials

Members:
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- Lisa Brasche
- Al Broz
- Bob Cunningham
- Carmen Delgado
- John Fabry
- Bob Guyotte
- Bruce Kotzian
- Chris Heizer
- Nancy Lane
- Stephanie Markos
- Scott Pitts
- Fred Sobeck

FAA NDI Training Design Panel Activities

3rd Quarter, 1992 - Initial draft of NDI Training Design Plan

4th Quarter, 1992 - Final draft of NDI Training Design Plan

2nd Quarter 1993 - Course objectives and outline established

3rd Quarter, 1993 - 2nd Quarter, 1994 - Course development

2nd Quarter 1994 - Initial course walkthrough

3rd Quarter, 1994 - Course prototype to be transferred to FAA Training Academy

FAA-CASR

Job Functions of the ASI

Certification - to evaluate the manner in which prospective air operators or air agencies intend to conduct business to insure compliance with all applicable FARs, the Federal Aviation Act of 1958 (FA Act) and FAA directives.

Audit/Evaluation - to verify that the certificate holder meets all regulatory requirements

Surveillance - to insure that compliance is maintained in the day to day operations of an air operator or air agency for the certificates that they hold

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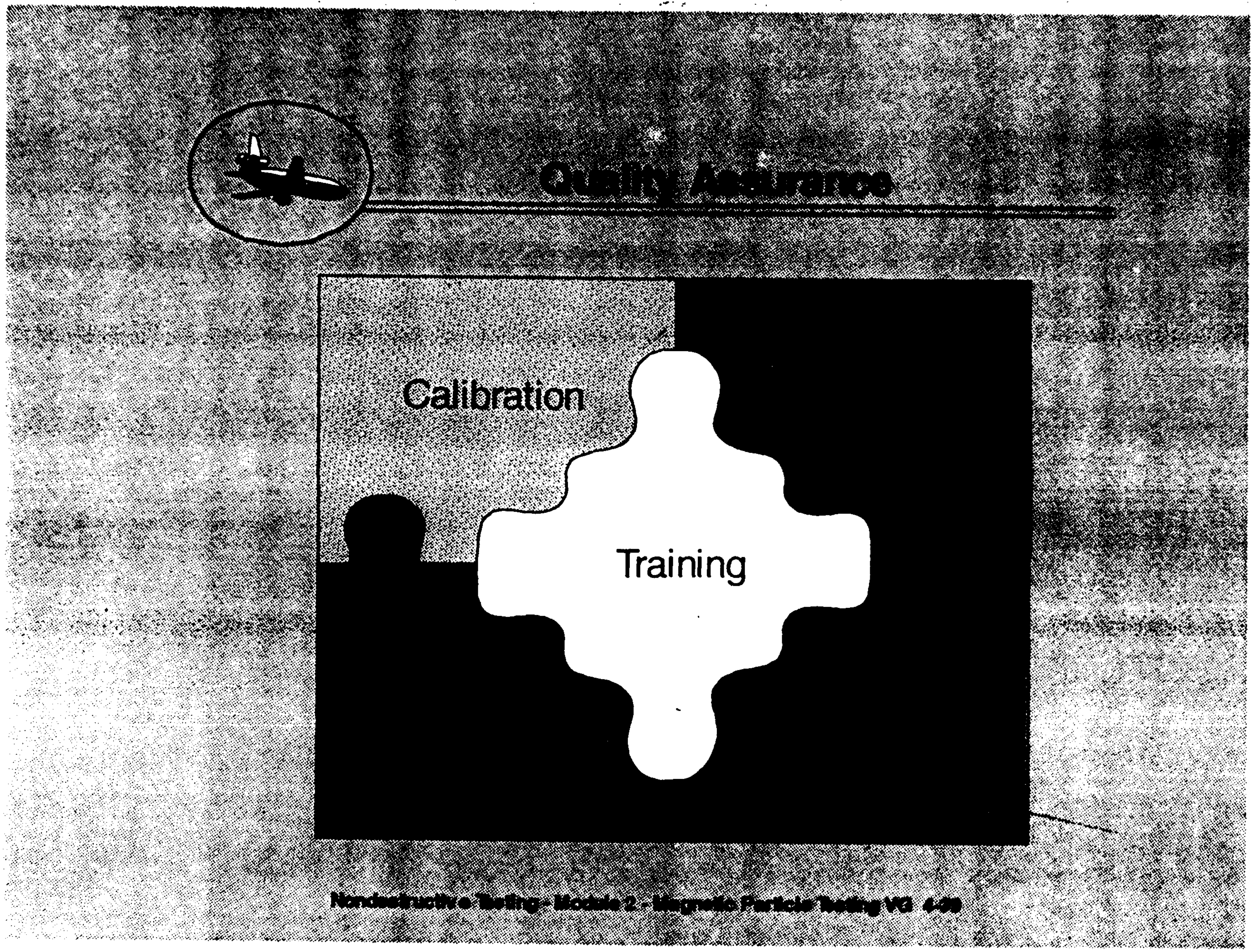
Course Objectives

- Identify various NDI methods and describe application on aircraft material and components.
- Determine applicable FAR requirements and other FAA guidance material that pertain to a given facility.
- Conduct a comprehensive evaluation of the facility or operators NDI system.
- Identify and define all requirements for a procedures handbook for conducting NDI, documentation and records of test operation and calibration of equipment and selection of NDI inspectors.
- Develop quality assurance tools necessary for ongoing surveillance of a facility or operators NDI system.


Quality Assurance
Calibration
Training
Nondestructive Testing - Module 2 - Magnetic Particle Testing VG

Course Outline

- Module I - Introduction
  - Responsibilities of ASIs
  - Application of NDI in Aviation Industry
  - Objectives
  - Generic Process for Evaluation of NDI
  - Systems
  - Summary
- Module II - NDI Methods
  - Overview
  - Visual Inspection
  - Penetrant Inspection
  - Magnetic Particle Inspection
  - Eddy Current Inspection
  - Ultrasonic Inspection
  - Radiography
- Module III
  - Certification
  - Audit and Evaluation
  - Surveillance
- Module IV
  - Review

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Generic Process for Evaluation of NDI Systems

- Documentation
- Organizational Structure
- Environment
- Calibration
- Training

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Summary of Course Content

- ASIs serves as evaluator in
  - certification
  - audit/evaluation
  - surveillance
- NDI methods are used to insure conti ed airworthiness
  - Visual Inspection
  - Penetrant Inspection
  - Magnetic Particle Inspection
  - Eddy Current Inspection
  - Ultrasonics Inspection
  - Radiography
- Generic process exists for evaluation of NDI systems
  - Documentation
  - Organizational structure
  - Environment
  - Calibration
  - Training

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Deliverables

- Lesson plans for use by Academy instructors
- Viewgraphs and other instructional tools
- Student exercises
- Student handbook and reference list

FAA-CASR

Project 2 Education and Training
Task 6 FAA NDI Course Development

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Dr. Robert L. Thomas Department of Physics Wayne State University Detroit, MI 48202 phone: (313) 577 2970 fax: (313) 577 7743 home: other:	Dr. Bruce Thompson FAA CASR Iowa State University 1915 Scholl Road Ames, IA 50011 phone: (515) 294 7864 fax: (515) 294 7771 home: other:
Mr. Chuck Tiffany 9 Westerly Lane Centerville, Ohio 45458 phone: (513) 433 6531 fax: home: (602) 329 1241 other:	Dr. Lalita Udpa FAA CASR Iowa State University 1915 Scholl Road Ames, IA 50011 phone: (515) 294 4623 fax: (515) 294 7771 home: other:

Invited Guests and Participants, Inspection Program Area Review, April 5-7, 1994

Mr. Doug VanOtterloo FAA CASR Iowa State University 1915 Scholl Road Ames, IA 50011 phone: (515) 294 2576 fax: (515) 294 7771 home: other:	Mr. Walt VanDuyne GE Aircraft Engines 111 Merchant Street Cincinnati, Ohio 45246 phone: (513) 552 2500 fax: (513) 552-6532 home: other:
Mr. Chris Vickers WL/Materials, WL/MLLP USAF 2230 Tenth Street WPAFB, OH 45433 phone: (513) 255 9795 fax: home: other:	Mr. Les Vipond AFS-302, Aircraft Maintenance Division FAA Headquarters 800 Independence Avenue, S.W. Washingtion, DC 20591 phone: (202) 267 3269 fax: home: other:
Mr. Al Voeller Maintenance and Engineering Center American Airlines P.O. Box 582809 MD 208 Tulsa, OK 74158-2809 phone: (918) 292 2861 fax: home: other:	Mr. John Wagner SAIC 2109 Air Park SE Albuquerque, NM 87105 phone: (505) 842 7709 fax: (505) 842 7798 home: other:
Mr. Dick Walingford FAA CASR Iowa State University 1915 Scholl Road Ames, IA 50011 phone: (515) 294 6788 fax: (515) 294 7771 home: other:	Dr. Pat Walter Aging Aircraft NDI Development and Demonstration Center (AANC) Sandia National Laboratories Organization 2752 PO Box 5800/ Mail Stop 0616 Albuquerque, New Mexico 87185 phone: (505) 844 5226 fax: (505) 844 8711 home: other:
Mr. Hans Weber President Weber Technology Application 7916 Laurelridge Road San Diege, CA 92120 phone: (619) 286 6660 fax: (619)-286-9467 home: other:	Mr. Bill Wilson Sandia National Laboratories MS 9005 P.O. Box 969 Livermore, CA 94550 phone: (510) 294 2326 fax: (510) 294 1337 home: other:

Invited Guests and Participants, Inspection Program Area Review, April 5-7, 1994

Dr. William P. Winfree Non Destructive Evaluation NASA Langley Research Center Mail Stop 231 Hampton, VA 23665-5225 phone: (804) 864 4963 fax: home: other:	Ms. Laurel Wittman ACM 510 FAA Technical Center Atlantic City International Airport New Jersey 08405 phone: (609) 485 6719 fax: (609) 485 6766 home: other:
Mr. Fred Workley National Air Transport Association 4226 King Street Alexandria, VA 22302 phone: (703) 845 9000 fax: (703) 845 8176 home: other:	Mr. Rich Yarges ANM-112, Transport Airplane Directorate, Aging Aircraft Programs FAA Northwest Mountain Region 1601 Lind Avenue, SW Renton, Washington 98055-4056 phone: (206) 227 2143 fax: 206 227-1320 home: other:
phone: fax: home: other:	phone: fax: home: other:
phone: fax: home: other:	phone: fax: home: other:
phone: fax: home: other:	phone: fax: home: other:

Aging Aircraft Program
FAA Technical Center
Atlantic City Int'l Airport
New Jersey 08405

20 June, 1994

Dear Invitee:

You and/or your chosen representatives are invited to participate in a review of the Inspection Sub-Program of the Aging Aircraft Research Program. The review will be held at the Center for Aviation Systems Reliability (CASR), Ames, Iowa April 5-7, 1994. A preliminary agenda is attached. CASR researchers have been requested to be available April 4 & 8 for individual interaction with the reviewers.

The purpose of the review is to solicit program feedback from a broad and diverse base of technical expertise. The invitees to the review include representatives from the airlines, aircraft manufacturers, and the Department of Defense, other experts in the technology of nondestructive inspection, the FAA Aging Aircraft Program managers and staff, members of the Technical Oversight Group on Aging Aircraft (TOGAA), members of the Airworthiness Assurance Nondestructive Inspection Working Group (AANWG), and the Director of the FAA Technical Center.

The review will encompass both the programmatic and organizational elements (the first half day) and the individual tasks under the program elements (remainder of the review). To enhance your ability to participate, you will be furnished reference material and a final agenda by early March. Included in that reference material will be a rating scheme for evaluation of individual tasks.

Your feedback as part of the team effort is needed to make the program as useful to the aviation industry as possible. In past reviews, AANWG and more recently TOGAA have made substantial improvements in the program, but both Al Broz and myself have not formally issued to reviewers feedback showing the impact of their review on the program. We now have a management strategy for the program that gives me the confidence to guarantee future feedback to each reviewer of either the disposition of his comments or their impact on the program.

Please accept my invitation to participate in this review. At your earliest possible convenience please inform Chris Smith of your intention to participate. He can be reached by phone at (609) 485 5221 or by fax at (609) 485 4569. I look forward to seeing you at the review.

Sincerely,

Christopher Smith
Manager, Aging Aircraft Inspection Sub-Program

Aging Aircraft Program
FAA Technical Center
Atlantic City Int'l Airport
New Jersey 08405

31 March, 1994

«mr» «first» «last»
«address1»
«address2»

Dear «mr» «last»:

Attached is the agenda for the April 5-7 review of the Aging Aircraft Program's Inspection Activities. You are also invited to spend Monday and/or Friday at CASR to interact directly with the CASR researchers. Attachment 2 is a list of invitees including all reviewers but only lead investigators. Attachment 3 is a comprehensive phone list of FAA points of contact and researchers. You are encouraged to contact any of these people for additional information on specific research initiatives.

Attachment 4 is some hotel and transportation information.

To avoid the perception of this being yet another 'data dump', we have organized the program a little differently this time. This year the emphasis has shifted from organizational (AANC, CASR, etc.) to programmatic (technology transfer, program areas, Research Program Initiatives, etc.) and from technology based presentations (eddy current, ultrasonics, etc.) to applications (crack detection, corrosion/disbond detection, corrosion detection, bond inspection). We hope this will change will make our meeting more productive.

At the review we will be providing you with a score sheet for rating both program areas as a whole and individual tasks within the program areas. Though the forms, which will have some room for comments, may be a little reductionist, there is simply too much material to focus on specific tasks for any great length of time. Attachment 5 is a sample of these forms and their instruction sheets.

To help you prepare for the meeting I have also attached some preliminary information for your review. Attachment 6 is a table of technology applications. A quick scan of this chart will give you a basic understanding of the application areas, flaw types, and technologies we are examining. Your feedback regarding this balance of activities will be solicited at the meeting. In commenting on that balance you may wish to examine Attachment 7 which is a listing of other organizations examining Aging Aircraft issues.

Attachment 8 consists of 10 viewgraphs covering the nature and status of the five Research Program Initiatives to be discussed at the review. While the RPI's are the definitive program document, they are periodically updated following the re-examination of government and industry requirements. Attachment 9 is a set of excerpts from the Inspection Sub-Program's *Requirements Document* covering the bulk of Aging Aircraft inspection activities. Keep in mind that this *Requirements Document* is new and in its formative stages.

The final two attachments present the organizational structure of the Sub-Program. While organizational structure is not to be emphasized at the Review, a knowledge of this structure will give you an understanding of the constraints and limitations of our Program. Attachment 10 is a chart showing the relationships of the several sponsoring and performing organizations associated or affiliated with the FAA. Attachment 11 is a list of Inspection Sub-Program tasks and their FY94 investigating organization.

We look forward to seeing you at the review,

Sincerely,

Chris Seher
Manager, Aging Aircraft Program

attachments:

1. agenda
2. list of invitees
3. list of FAA and contractor points of contact
4. directions and hotel information
5. program and task score sheets
6. table of technology applications
7. table of sponsoring organizations
8. RPI description and status sheets
9. Inspection Sub-Program Requirements Document
10. chart of FAA affiliate structure
11. table of activities and investigating organizations

Aging Aircraft Inspection Program Review
April 5-7, 1994
Center for Aviation Systems Reliability
Ames, Iowa

TUESDAY, APRIL 5

8:00	*Refreshments*	
8:20	**Welcome/Logistics**	Seher/Chimenti
8:30	**Purpose and Goals of Meeting**	Seher/Broz
8:45	**Program Overview**	C. Seher
9:15	**Managing the Tech Transfer Challenge**	C. Seher
9:30	**CASR Activities in Last Year**	D. Chimenti
10:15	*Break*	
10:30	**AANC Activities in Last Year**	P. Walter
11:15	**Laboratory Tour and Demonstrations - NSF Lab**	
12:00	*Lunch*	
12:45	**Validation and Tech Transfer**	Walter
	Validation:	
13:10	MOI validation	F. Spencer, SNL
13:30	Cost Benefit Analysis Protocol (with MOI example)	V. Brechling, NWU
13:50	Assessment of Eddy Current Inspection Equipment	F. Spencer, SNL
14:10	Evaluation of Scanners for C-Scan Imaging	W. Shurtleff, SNL
14:30	*Break*	
	Tech Transfer:	
14:50	Tech Transfer Process and Its Implementation on DC9 Wingbox	M. Ashbaugh, AANC
15:10	Proposed Self Compensating UT Probe Solution for DC9 Wingbox	I. Komsky, NWU
15:30	Prioritized Tech Transfer Candidates (CASR)	CASR directors
16:30	AANC Techg Transfer FY 94- 95 Plans	Walter
17:00	*Adjourn*	

WEDNESDAY, APRIL 6

8:00	*Refreshments*	
8:15	**Inspection Reliability and Visual Inspection**	C. Smith, FAA TC
8:25	Eddy Current Inspection Reliability Experiment	F. Spencer, SNL
9:00	Visual Inspection Program	F. Spencer, SNL
9:20	Computational Models for Inspection Engineering	J. Gray, ISU
9:40	*Break*	
10:00	Enhanced Visual Inspection of Fuselage Skins (D-Sight)	J. Komerosky
10:20	Enhanced Visual Inspection Tools for Airframe Structures	W. Shurtleff, SNL
10:30	**Laboratory Tour and Demonstrations - Individual Labs**	
11:30	*Lunch*	
12:30	**Techniques for Flaw Detection**	C. Smith, FAA TC
	Crack Detection Technology for Fastened Skins:	
12:40	Local Laser Based UT	J. Achenbach, NWU
13:00	Self Compensating UT	I. Komsky, NWU
	Skin Splice Disbond/Corrosion Inspection Technology:	
13:20	Thermal Wave Imaging	R. Thomas, WSU
14:05	Dual Band Infrared Imaging	N. DelGrande, LLNL
14:25	Ultrasonic Characterization of Adhesively Bonded Panels	D. Hsu, ISU
14:45	*Break*	
	Technology for Bond Inspection:	
15:00	Possible Application of LTI's Shearography to Lap Splice Inspections	Dave Galella
15:10	Coherent Widefield Optical Imaging	S. Krishnaswamy, NWU
15:30	Shearographic Inspection	J. Genin, NMSU
15:50	UT Lamb Wave Disbond Detection	J. Rose, Penn State
	Corrosion Inspection Technology:	
16:10	Eddy Current Methods for Corrosion Detection	J. Moulder, ISU
16:30	Radiographic Methods for Corrosion Detection	Gray/Achenbach, ISU/NWU
16:50	*Adjourn*	

THURSDAY, APRIL 7

8:00	*Refreshments*	
8:10	**Automation and Robotics**	D. Galella, FAA TC
8:20	Robotic Device for Fastened Skins	W. Kaufman, CMRI
9:00	Neural Nets for Eddy Current Inspection of Wheels & Turbine Blades	Udpa/Peshkin, CASR
9:20	Image Processing for Burner Can Radiography	Walingford/Sahakian, CASR
9:40	*Break*	
9:50	**Training and Information Dissemination**	J. Fabry, FAA TC
10:00	Innovative Process for Technology Transfer	A. Gellman, NWU
10:30	Job Task Analysis	G. Krulee, NWU
10:50	Aviation Inspector Training Course Development	L. Broz, ISU
11:10	X-ray training software	J. Gray, ISU
11:30	**Executive Session: FAA, TOGAA, AANWG only (Lunch: all others)**	
12:30	**Lunch: FAA, TOGAA, AANWG**	
13:00	**Open Feedback to Presentors from FAA, TOGAA, and AANWG**	
13:30	*Adjourn*	

Aging Aircraft Inspection Program Review - Invited Participants

Achenbach, Jan D.	Northwestern University	(708) 491 5527
Bahr, Behnam	Wichita State University	(316) 689 3402
Bobo, Stephen	DOT/VNTSC	(617) 494-2165
Borenstein, Bernard	FAA LAX FSDO	(310) 215 2150
Borfitz, Michael	FAA New England Region	(617) 273 7068
Brandewie, Michael	FAA Technical Center	(609) 485 6085
Brasche, Lisa J. H.	Iowa State University	(515) 294 5227
Brechling, Venessa J.	Northwestern University	(708) 491 2283
Brewer, John	DOT/VNTSC	(617) 494 2554
Broz, Alfred L.	FAA New England Region	(617) 238 7105
Casterline, Roger	United Airlines - SFOEG	(415) 634 4780
Chimenti, Dale	Iowa State University	(515) 294 5021
Cordell, Tobey	USAF/WL/MLLP	(513) 255 9802
Curtis, Dayton	FAA Northwest Mountain Region	(206) 227 2109
Del Grande, Nancy	Lawrence Livermore National Labs	(510) 422 1010
Dolan, Keneth	Lawrence Livermore National Labs	(510) 422 1010
Easton, Locke	FAA New England Region	(617) 238 7114
Erickson, Steven R.	Air Transport Association	(202) 626 4134
Fabry, John	FAA Technical Center	(609) 485 6132
Forney, Don	Universal Technology Corporation	(513) 426 8530
Flournoy, Thomas	FAA Technical Center	(609) 485 5327
Galella, Dave	FAA Technical Center	(609) 485 5784
Gehl, Steve	Electric Power Research Institute	(415) 855 2770
Gellman, Aaron J	Northwestern University	(708) 491 7286
Goranson, Ulf	Boeing Commercial Airplane Group	(206) 237 9909
Green, Robert	Johns Hopkins University	(410) 516-6115
Hagemaier, Donald J.	Douglas Aircraft Co.	(213) 593 7304
Heyman, Joseph S.	NASA Langley Research Center	(804) 864 4970
Hoggard, Amos	McDonnell Douglas Aircraft Co.	(213) 593 1843
Johnson, Richard	FAA Technical Center	(609) 485 4828
Kaufman, William M.	Carnegie Mellon University	(412) 268-3190
Keil, William C.	Regional Airline Association	(202)857-1170
Komorowski, Jerzy P.	National Research Council Canada	(613) 993 3999
Kotzian, Bruce	FAA Great Lakes Region	(612) 725 4355
Gill Krulee	Northwestern University	(708) 491 8048

Aging Aircraft Inspection Program Review - Invited Participants (continued)

LaRiviere, Steve G.	Operations Technology	(206) 234 8052
Lewis, Jesse	Aircraft Engineering Division	(202) 267 9287
Lincoln, John W.	US Airforce ASD/ENFS	(513) 255 6879
MacLeod, Sarah	Aeronautical Repair Station Association	(708) 739 9543
Mar, Jim	TOGAA	(408) 373 3449
Miller, Nelson	FAA Tech Center	(609) 485 4464
Miller, William	Transport Canada Aviation	(613) 952 4388
Mills, Larry	United Airlines	(415) 634 4677
Morgan, James	TWA	(816) 891 4128
Nethercutt, Burl	American Airlines	(918) 292 3275
Nuss, Marv	FAA Central Region	(816) 426 3241
Register, Jeff	Northwest Airlines	(612) 726 7274
Rose, Joseph	Pennsylvania State University	(814) 863 8026
Rummel, Ward	Martin-Marietta	(303) 977-1751
Safeer, Harvey	FAA Technical Center	(609) 485 6641
Seher, Chris	FAA Technical Center	(609) 485 6787
Sexton, Bob	FAA Central Region	(816) 426 3241
Shepherd, Bill	FAA Headquarters	(202) 366 6910
Shih, William	PRI Instrumentation	(213) 791 1774
Smith, Christopher	FAA Technical Center	(609) 485 5221
Sobeck, Fred	FAA Washington Headquarters	(202) 267 7355
Stauffer, Warren	TOGAA	(714) 498 2917
Swift, Thomas	FAA Northwest Mountain Region	(310) 988 5205
Taylor, Jim	University of Southern California	(213) 454 2604
Taylor, Martin	TOGAA	(813) 383 7776
Thomas, Robert L.	Wayne State University	(313) 577 2970
Tiffany, Chuck	TOGAA	(513) 433 6531
VanDuyne, Walt	GE Aircraft Engines	(513) 552 2500
Vipond, Les	FAA Headquarters	(202) 267 3269
Voeller, Al	American Airlines	(918) 292 2861
Walter, Pat	Sandia National Laboratories	(505) 844 5226
Weber, Hans	Weber Technology Application	(619) 286 6660
Winfree, William P.	NASA Langley Research Center	(804) 864 4963
Workley, Fred	National Air Transport Association	(703) 845 9000
Yarges, Rich	FAA Northwest Mountain Region	(206) 227 2143

Inspection Sub-Program Points of Contact

199 Techniques for Flaw Detection	Contractor Point of Contract		FAA Point of Contact	
Local Laser-Based Ultrasonics	Jan Achenbach Northwestern University	(708) 491 5527	Dave Galella	(609) 485 5784
Self Compensating Ultrasonic Instrument	Igor Komsky Northwestern University	(708) 491 7950	Dave Galella	(609) 485 5784
Acoustic Emission Evaluation of Aircraft Panels	Mike Horn Grumman Aerospace	(516) 346 8280	Dave Galella	(609) 485 5784
Portable Holography	John Baird CAA-Australia		Dave Galella	(609) 485 5784
Optical Interferometry	Sridhar Krishnaswamy Northwestern University	(708) 491 4006	Dave Galella	(609) 485 5784
Thermal Wave Imaging of Adhesive Bonds	Bob Thomas Wayne State University	(313) 577 2970	Dave Galella	(609) 485 5784
Ultrasonic Characterization of Adhesive Bonds	Dave Hsu Iowa State University	(515) 294 2501	Dave Galella	(609) 485 5784
Dual-Band Infrared Imaging for Aircraft Inspection	Nancy Del Grande Lawrence Livermore	(510) 422 1010	Dave Galella	(609) 485 5784
Eddy Current Methods for Corrosion Detection	John Moulder Iowa State University	(515) 294 9750	Dave Galella	(609) 485 5784
Radiographic Methods for Corrosion Inspection	Jan Achenbach Northwestern University	(708) 491 5527	Chris Smith	(609) 485 5221
Air Coupled Ultrasonics	Dale Chimenti Iowa State University	(515) 294 5021	Dave Galella	(609) 485 5784
Ultrasonic Lamb Wave Disbond Detection	Joe Rose Penn State University	(814) 863 8026	Dave Galella	(609) 485 5784
Fiber Optics Advanced Inspection Research	C. Yu North Carolina A&T		Tom Flournoy	(609) 485 5327
200 Inspection Automation and Robotics	**Contractor Point of Contract**		**FAA Point of Contact**	
Neural Nets for Signal Classification	M. Peshkin Northwestern University	(708) 491 4630	Chris Smith	(609) 485 5221
Image Processing for Radiographic Inspection	Richard Walingford Iowa State University	(515) 294 6788	Chris Smith	(609) 485 5221
Surface Crawling Robot for Fuselage Inspection	William Kaufmann Carnegie Mellon RI	(412) 268 3190	Dave Galella	(609) 485 5784
Technology for Robotic Inspection of Aircraft	Beham Bahr Wichita State University	(316) 689 3402	Dave Galella	(609) 485 5784
Simulation of Automated Inspection Devices	Donna Anderson DOI Mines	(412) 892 6714	Dave Galella	(609) 485 5784
202 Inspection of Engine Parts	**Contractor Point of Contract**		**FAA Point of Contact**	
Neural Nets for Engine Inspection	Lalita Udpa Iowa State University	(515) 294 4623	Chris Smith	(609) 485 5221
Detection of Hard Alpha in Titanium Alloys	Lisa Brasche Iowa State University	(515) 294 5227	Chris Smith	(609) 485 5221
Engine Study (Actuarial Analysis)	Bruce Richter SAIC	(512) 737 3933	Dave Galella	(609) 485 5784

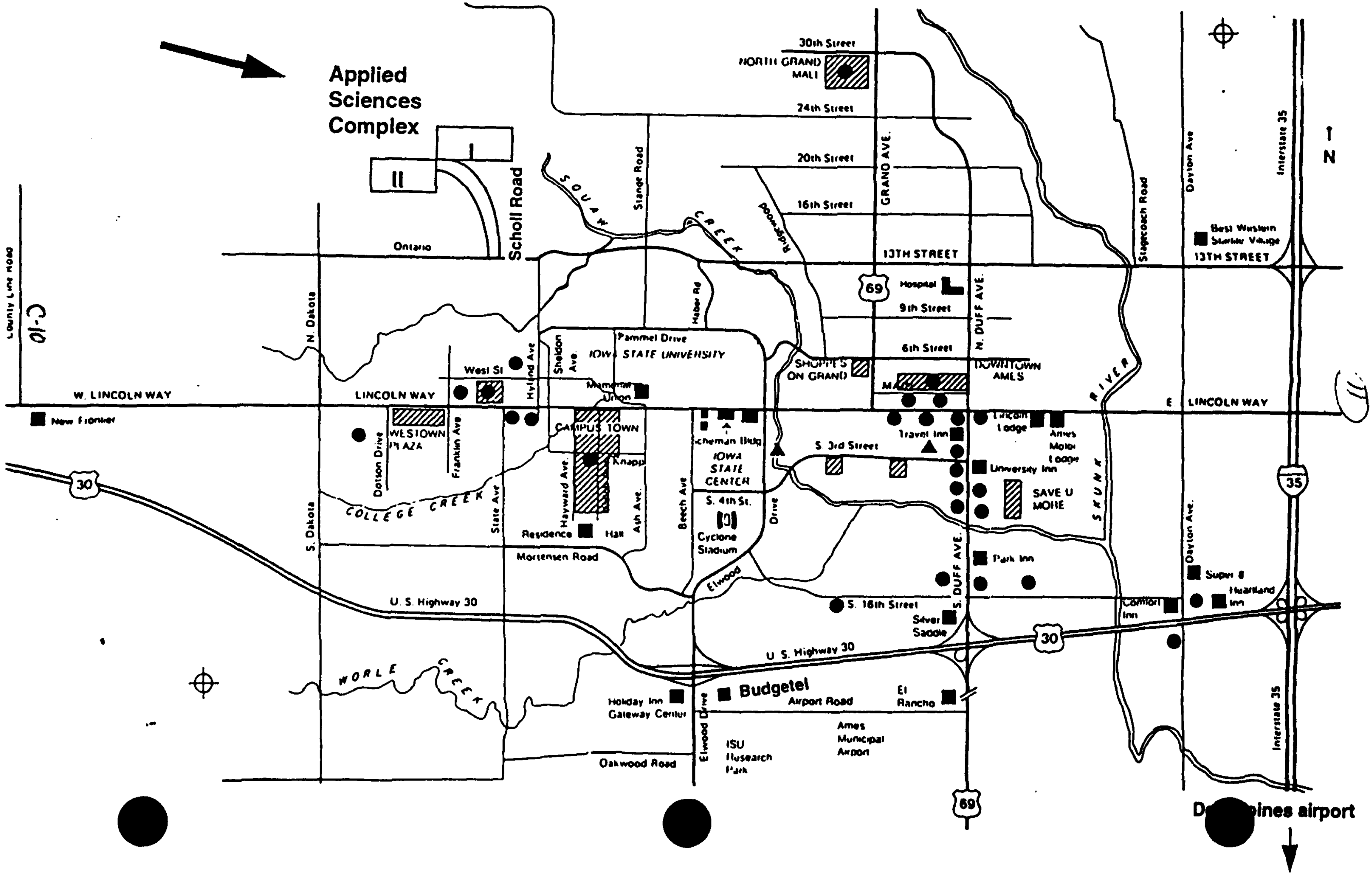
Inspection Sub-Program Points of Contact (Continued)

202 Inspection of Engine Parts	Contractor Point of Contract		FAA Point of Contact	
Fundamental Studies of Titanium	Jon Bartos GE Aircraft Engines	(513) 552 4625	Burce Fenton	(609) 485 5158
rasonic Inspection During the Production Process	Jon Bartos GE Aircraft Engines	(513) 552 4625	Wayne Shade	(609) 485 4009
Disk Inspection Reliability	Bruce Thompson Iowa State University	(515) 294 7864 am (515) 294 9649 pm	Chris Smith	(609) 485 5221
Eddy Current Inspection During Engine Service	Kevin Smith Pratt & Whitney	(407) 796 6536	Chris Smith	(609) 485 5221
204 Visual Inspection	**Contractor Point of Contract**		**FAA Point of Contact**	
Reliability Assessment using Maintenance Data -Visual	John Brewer Volpe TSC	(617) 494 2554	Chris Smith	(609) 485 5221
Visual Acuity Survey			Dave Galella	(609) 485 5784
Enhanced Visual Inspectin Program for Airlines	Robert Lutzinger Wilson Composite	(916) 989 4812	Dave Galella	(609) 485 5784
Visual Inspection Probability of Detection Experiment	Floyd Spencer Sandia National Labs	(505) 844 5647	Chris Smith	(609) 485 5221
Visual Inspection Enhancement Technologies	William Shurtleff Sandia National Labs	(505) 844 3500	Dick Johnson	(609) 485 4828
Corrosion Detection using D-Sight	Jersey Komorsoky Transport Canada	(613) 993 3999	Dave Galella	(609) 485 5784
205 Inspection Reliability	**Contractor Point of Contract**		**FAA Point of Contact**	
Inspection Prioritization Methodology	Benham Bahr Wichita State University	(316) 689 3402	Dave Galella	(609) 485 5784
Reliability Assessment using Maintenance Data	John Berwer Volpe TSC	(617) 494 2554	Chris Smith	(609) 485 5221
Eddy Current and MOI Reliability Experiment	Floyd Spencer Sandia National Labs	(505) 844 5647	Chris Smith	(609) 485 5221
Detection of Subsurface Corrosion using Improved MOI	Bill Shih PRI	(310) 378 0056	Dave Galella	(609) 485 5784
NDI for Commuter Aircraft	Ron Smith AEA Technology	011 0235 32512	Dave Galella	(609) 485 5784
Eddy Current Calibration and Standardization	John Moulder Iowa State University	(515) 294 9750	Dave Galella	(609) 485 5784
Failure Property Relationships of Adhesive Bonds	H. Aglan Tuskegee University	(205) 727 8973	Dave Galella	(609) 485 5784
Develop Computer Models for Inspection Simulation	Joe Gray Iowa State University	(515) 294 9737	Chris Smith	(609) 485 5221
Coherent Optics Metrology Techniques	Mike Valley New Mexico State Univer	(505) 646 6533	Dave Galella	(609) 485 5784
Application of Models to Specific Inspections	Joe Gray Iowa State University	(515) 294 9737	Chris Smith	(609) 485 5221
Other Activities	**Contractor Point of Contract**		**FAA Point of Contact**	
Johns Hopkins Center for Nondestructive Evaluation	Bob Green Johns Hopkins CNDE	(410) 516 6115	Dave Galella	(609) 485 5784
a State Center for Nondestructive Evaluation	Don Thompson Iowa State CNDE	(515) 294 8152	Chris Smith	(609) 485 5221

Ames and Iowa State University

Directions from the Des Moines airport to Ames

Exit the airport and turn right onto Fleur Drive; then left onto Army Post Road. Follow Army Post Road to S.E. 14th Street. Turn left onto S.E. 14th and follow this street until you have the opportunity to exit right onto I235 east. This interstate will blend into I35 north. Ames is approximately 30 miles north of Des Moines. You may exit the interstate at Ames at either the Highway 30 or the 13th Street interchange.



C-10

Lodging Information for FAA Review

Rooms have been blocked at the following motels: the availability dates are listed with each motel. When making your reservations ask for the block of rooms set aside for "FAA REVIEW"

Motel	Address	Telephone	Number of rooms/Rate
Heartland Inn	Exit I35 & highway 30	515-233-6060	8 @ $42.90 incl. tax 7 @ $46.20 incl. tax Available through 3-31-94
Comfort Inn	Exit I35 & highway 30	515-232-0689	10 @ $38.50 incl.tax Available through 3-25-94
Holiday Inn Gateway Center	Exit I35 & highway 30	515-292-8600	40 @ $55.00 Available through 3-18-94 FAX 515-292-4446
Best Western Starlite	Exit I35 & 13th street	515-232-9260	8 @ $48.40 incl. tax (poolside) 2 @ $46.20 incl. tax Available through 3-18-94

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Instructions for Inspection Review Score Sheet

The attached score sheets are meant to serve as measure of the progress and direction of the Aging Aircraft Program's Inspection Sub-Program. Other sources of feedback will include comments made during and after the review either in public or private, and correspondence and follow-up conversations. No single source of information will be used in isolation to define or direct the Inspection Sub-Program.

The first score sheet allows reviewers to comment on Inspection Sub-Program elements above the task level. This score sheet will be reflective of the Sub-Program management performance by the FAA and its contractors. The second set of score sheets will address specific tasks and will be reflective of the management and technical merit of individual tasks.

Instructions for Sub-Program Management Score Sheet:

1. Each score sheet is indexed in the upper left corner with the highlighted name of the group or organization to which the reviewer belongs (TOGAA AANWG OPERATOR MANUFACTURER FAA RESEARCHER OTHER). In the example score sheet attached OPERATOR is highlighted. Actual score sheets will be distributed at the meeting. At that time, please be sure that you have been given the correct score sheet.
2. Sub-Program elements are arranged in order of presentation. The element description is followed in parentheses by the FAA point of contact. A list of FAA points of contact and their phone numbers is attached to these score sheets.
3. The column marked 'priority' should be filled-in with your assessment of the RPI's importance. Please use the following code
   - 0 = no requirement
   - L = low priority
   - M = medium priority
   - H = high priority
4. The column marked 'grade' should be filled-in with your assessment of the RPI's success to date. The grade should be reflective of **both** task management and technical merit. Please use the following code
   - A = excellent, no redirection required
   - B = good, but consider some redirection
   - C = fair, but significant redirection is necessary
   - D = borderline acceptable, major restructuring or cancellation
   - F = no merit, cancellation imperative

6. The column marked comments is for your brief comments. Please include additional pages if you wish.
7. All sheets will be collected on April 7 after the final presentations.

Instructions for Task Level Score Sheets:

1. Each score sheet is indexed in the upper left corner with the highlighted name of the group or organization to which the reviewer belongs (TOGAA AANWG OPERATOR MANUFACTURER FAA RESEARCHER OTHER). In the example score sheet attached OPERATOR is highlighted. Actual score sheets will be distributed at the meeting. At that time, please be sure that you have been given the correct score sheet.
2. Tasks are arranged in order of presentation. The task description is followed in parentheses by the FAA point of contact and the principal investigator. A list of FAA Points of Contact and Principal Investigator Phone Numbers is attached to this score sheet.
3. The column marked 'priority' should be filled-in with your assessment of the initiatives importance. Please use the following code

    0 = no requirement

    L = low priority

    M = medium priority

    H = high priority
4. The column marked 'grade' should be filled-in with your assessment of the initiatives success to date. The grade should be reflective of **both** task management and technical merit. Please use the following code

    A = excellent, no redirection required

    B = good, but consider some redirection

    C = fair, but significant redirection is necessary

    D = borderline acceptable, major restructuring or cancellation

    F = no merit, cancellation imperative
5. The column marked FY94 Tech Transfer should be filled-in with your assessment of the importance of engaging in near-term technology transfer. Please use the following code

    I = Immediate tech transfer candidate

    95 = consider tech transfer in FY95 after some additional development

    LT = no tech transfer possible in near- to mid-term, Long Term only
6. The column marked 'comments' is for your brief comments. Please include additional pages if you wish.
7. All sheets will be collected on April 7 after the final presentations.

TOGAA AANWG **OPERATOR** MANUFACTURER FAA RESEARCHER OTHER NAME ____________________

program element	**comments**
Goals of Program (Broz)	
Overall Program Approach (Seher)	
Tech Transfer Approach (Seher)	
CASR Project - Overall (Chimenti)	
AANC Project - Overall (Walter)	

Research Program Initiative	**priority**	**grade**	**comments**
Validation and Tech Transfer (Johnson)			
Inspection Reliability & Visual Inspection (Smith)			
Automation & Robotics (Galella)			
Techniques for Flaw Detection (Smith)			
Training and Information Dissemination (Fabry)			

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Validation and Tech Transfer				
task	priority	grade	1994 Tech Transfer	comments
MOI Validation at AANC (Johnson/Spencer)			NA	
Cost Benefit Analysis Protocol with MOI example (Johnson/Brechling)			NA	
Assessment of Eddy Current Inspection Equip (Johnson/Spencer)			NA	
Assessment of Scanners for C-Scan Imaging (Johnson/Spencer)			NA	
Tech Transfer Process and its Implementation (Johnson/Walter)			NA	
Self Compensating UT for DC 9 Wingbox (Komsky/Galella)		NA		
Candidate Tech Transfer Activities				
UT w/ Dripless Bubler and Low Frequency Probe (Galella/Hsu)		NA		
Low-cost Photodensitometer for X-Ray Imaging (Gray/Smith)		NA		
Probe Calibration and Standards (Galella/Moulder)		NA		
X-Ray Backscatter for Corrosion Detection (Smith/Achenbach)		NA		
Self Compensating UT for DC 9 Wingbox (Komsky/Galella)		NA		
Shearographic Inspection for Disbonds (Galella/Krishnaswam)		NA		
Thermal Wave Imaging (Thomas/Galella)		NA		

TOGAA AANWG **OPERATOR** MANUFACTURER FAA RESEARCHER OTHER NAME ____________

Inspection Reliability and Visual Inspection

task	priority	grade	1994 Tech Transfer	comments
Eddy Current Inspection Reliability Experiment (Smith/Spencer)			NA	
Visual Inspection Program (Smith/Spencer)			NA	
Computer Codes for Inspection Simulation (Smith/Gray)			NA	
Enhanced Visual Inspection for Corrosion using D-Sight (Galella/Komerosky)			NA	
Enhanced Visual Inspection Tools for Airframes (Johnson/Shurtleff)			NA	

TOGAA AANWG **OPERATOR** MANUFACTURER FAA RESEARCHER OTHER NAME ____________

Technologies for Flaw Detection

task	priority	grade	1994 Tech Transfer	comments
✓ Local Laster Based Ultrasonics (Galella/Achenbach)				
✓ Self Compensating Ultrasonics Probe (Galella/Komsky)				
✓ Thermal Wave Imaging (Galella/Thomas)				
✓ Dual Band Infrared Imaging (Galella/DelGrande)				
Ultrasonic Characterization of Adhesive Bonds (Galella/Hsu)				
✓ Coherent Widefield Optical Imaging (Galella/Krishnaswamy)				
✓ Shearographic Inspection Modeling (Galella/Valley)				
✓ Ultrasonic Lamb Wave Disbond Detection (Galella/Rose)				
✓ Eddy Current Methods for Corrosion (Galella/Moulder)				
✓ Radiography for Corrosion Detection (Smith/Gray)				

TOGAA AANWG **OPERATOR** MANUFACTURER FAA RESEARCHER OTHER NAME ____________

Automation & Robotics

task	priority	grade	1994 Tech Transfer	comments
Robotic Devices for Fastened Skins (Galella/Kaufman)				
Neural Nets for Wheel Inspeciton (Smith/Udpa, Peshkin)				
Image Processing for X-ray (Smith/Walingford, Sahakain)				

Training and Information Dissemination

task	priority	grade	1994 Tech Transfer	comments
Innovative Process for Tech Transfer (Fabry/Gellman)			NA	
Job Task Analysis/Visaual Task Descriptors (Fabry/Krulee)			NA	
Aviation Inspector Training Course Development (Broz/Brasche)			NA	
X-ray Training Software (Smith/Brasche)			NA	

Technology Applications

199 Techniques for Flaw Detection	Application Area	Flaw Type	Technology
Local Laser-Based Ultrasonics	fuselage skins, general airframe	cracks	ultrasonic
Self Compensating Ultrasonic Instrument	fuselage skins, wing skins	cracks	ultrasonic
Acoustic Emission Evaluation of Aircraft Panels	fuselage skins	cracks	acoustic emission
Portable Holography	fuselage skins	cracks	coherent optics
Optical Interferometry	fuselage skins	disbonds, cracks	coherent optics
Thermal Wave Imaging of Adhesive Bonds	fuselage skins	disbonds, corrosion	thermal wave
Ultrasonic Characterization of Adhesive Bonds	fuselage skins	disbonds, corrosion	ultrasonic
Dual-Band Infrared Imaging for Aircraft Inspection	fuselage skins, wing skins	disbonds, corrosion	infrared
Eddy Current Methods for Corrosion Detection	fuselage skins, wing skins	corrosion	eddy current
Radiographic Methods for Corrosion Inspection	fuselage skins	corrosion	radiography
Air Coupled Ultrasonics	fuselage skins, composites	disbonds, delamination	ultrasonic
Ultrasonic Lamb Wave Disbond Detection	fuselage skins	disbonds	ultrasonic
Fiber Optics Advanced Inspection Research	general airframe	material degradation	infrared
200 Inspection Automation and Robotics	**Application Area**	**Flaw Type**	**Technology**
Neural Nets for Signal Classification	aircraft wheels	cracks	signal processing
Image Processing for Radiographic Inspection	burner can	cracks	signal processing
Surface Crawling Robot for Fuselage Inspection	fusleage skins, wing skins	cracks/corrosion	robotics
Technology for Robotic Inspection of Aircraft	fuselage skins, wing skins	cracks/corrosion	robotics
Simulation of Automated Inspection Devices	fuselage skins, wing skins	cracks/corrosion	computational modeling

Technology Applications (Continued)

202 Inspection of Engine Parts	Application Area	Flaw Type	Technology
Neural Nets for Engine Inspection	burner can	cracks	signal processing
Detection of Hard Alpha in Titanium Alloys	rotating components	inclusions	ultrasonic
Engine Study (Actuarial Analysis)	static engine cases	weld cracks	ultrasonic, eddy current
Fundamental Studies of Titanium	rotating components	inclusions	n/a
Ultrasonic Inspection During the Production Process	rotating components	inclusions, cracks	ultrasonic
Eddy Current Inspection During Engine Service	rotating components	cracks	eddy current, ultrasonic
204 Visual Inspection	**Application Area**	**Flaw Type**	**Technology**
Reliability Assessment using Maintenance Data - Visual	general airframe	cracks	visual
Visual Acuity Survey	general airframe	cracks	x-ray, visual
Enhanced Visual Inspectin Program for Airlines	general airframe	cracks, corrosion	enhanced visual
Visual Inspection Probability of Detection Experiment	to be determined	cracks	visual
Visual Inspection Enhancement Technologies	general airframe	cracks, corrosion	enhanced visual
Corrosion Detection using D-Sight	fuselage skins, wing skins	corrosion, crack	enhanced visual
205 Inspection Reliability	**Application Area**	**Flaw Type**	**Approach/Technology**
Inspection Prioritization Methodology	airframe general	all	n/a
Reliability Assessment using Maintenance Data	general airframe	cracks	statistical analysis
Eddy Current and MOI Reliability Experiment	lap splice	cracks	experiment, eddy current
Detection of Subsurface Corrosion using Improved MOI	fuselage skins	corrosion	electromagnetic
NDI for Commuter Aircraft	general airframe	cracks, corrosion	survey
Eddy Current Calibration and Standardization	general airframe	cracks, corrosion	hardware tool, eddy current
Failure Property Relationships of Adhesive Bonds	skin bonds	disbonds	experiment
Develop Computer Models for Inspection Simulation	general airframe	cracks	computational model, EC, x-ray
Coherent Optics Metrology Techniques	fuselage skins	disbonds	coherent optics
Application of Models to Specific Inspections	wing spar	cracks	computational model, x-ray

Sponsoring Organizations and Activities

FAA Aging Aircraft Structural Integrity (RPIs)
Structural Integrity of Commuters
Investigation of Corrosion Fatigue Interaction
Aging Aircraft Engine Life Predictive Methodologies
Widespread Fatigue Damage
Effects of Repair on Structural Integrity
Measurement and Analysis of Flight Loads for Transport Airplanes
Measurement and Analysis of Flight Loads for Commuter Airplanes
FAA Aging Aircraft Maintenance and Inspection (RPIs)
Alternative Strategies for Structural Repair and Rehabilitation
Aircraft Maintenance and Repair Procedures Development
Maintenance Corrosion Protection Procedures Development
Job Task Analysis
Proficiency and Equipment Standards
Training and Information Dissemination
Techniques for Flaw Detection
Inspection of Engine Components
Inspection Automation and Robotics
Inspection System Demonstration, Validation, and Tech Transfer
Visual Inspection
Inspection Reliability
FAA Structural Airworthiness (RPIs)
Composite Repairs for Aircraft Structures
Composites Handbook Development
NDI for Advanced Materials
Mechanical Property Testing for Advanced Materials
Composite Structure Damage Tolerance
Certification Issues for Structural Design Detail
Durability of Joints in Composite Structures
Certification of New Materials/Forms
In-Service Maintenance and Inspection of Composites
Probabilistic Design Concepts for Composite Structures

Sponsoring Organizations and Activities (continued)

NASA Aging Aircraft Structural Integrity (Approach)
Crack Initiation & Growth Studies
Mixed-Mode Loading
Multiple-Site Multiple-Element Residual Strength
Computational Models
Structural Details & Residual Strength
Global Local Methodology Development
Nonlinear Stiffened-Shell Analysis
Experimental Verification
NASA Aging Aircraft Inspection (Approach)
Disbond Detection
Corrosion Detection
Crack Detection
Computational Models
Tech Transfer
AF Office of Scientific Research Aging Aircraft (Working Groups)
Material Damage Behavior
Corrosion/Fatigue
Structural Integrity Assessment and Life Extension Methodology
Nondestructive Evaluation
USAF Materiel Command
Corrosion
Structures
Analysis/Life Prediction

NASA Langley Aging Aircraft Activities

Structural Integrity Analysis Methodology
Compendium of Analytical K-Solutions (ZIP3D)
PC-Based Computer Code to Compute K-Solutions (FRANC2D)
PC-Base Closure Model to Compute Crack Growth (FASTRAN)
Finite Element Shell Code (STAGS)
Adaptive Remeshing (RRANC3D)
Fracture Criteria for Mixed-Mode Loadings (ZIP2D)
Quantitative Nondestructive Inspection Technology
Reverse Geometry Radiographic Assessment of Corrosion
Low Cost Portable Eddy Current Crack Detection Probe (Simpson Probe)
Portable Ultrasonic Bond Detection Instrument
Low Cost Eddy Current Thickness/Corrosion Probe
Linear Array Ultrasonic Bond Detection Instrument
Portable Thermal Corrosion Detection Instrument
Lamb Wave Area Corrosion Detection Instrument for Lap Splices
Optics and Coherent Optics Aircraft NDE System (Dynamic Speckle and Shearography)
Magneto-Optic Airframe Integrity NDE System (in cooperation with PRI)
Multiparameter Neural Network Based Field Instrument for Corrosion in Lap Splices

Air Force Office of Scientific Research Programs

Materials Degradation and Fatigue in Aerospace Structures	
Environmental Degradation of Fatigue in Aircraft Structural Materials	MIT
Materials Degradation and Fatigue in Aerospace Structures	Purdue University
Characterization of Materials Degradation due to Corrosion & Fatigue	UCLA
Fundamental Study on Predicting Material Degradation & Fatigue of Ceramics	University of Florida
Materials Degradation and Fatigue Under Extreme Conditions	University of Illinois
Advanced Instrumentation and Measurements for Early NDE of Damage	Vanderbilt & Northwestern
Detection and Prevention of Corrosion in Aging Aircraft Structures	
Nondestructive Detection and Characterization of Corrosion in Aircraft	Iowa State University
Corrosion & Fatigue of Al Alloys: Chemistry, Micromechanics & Reliability	Lehigh University
NDI of Corrosion and Fatigue by Laser Speckle Sensor and Laser Moiré	State University of NY
STM Study of the Morphology & Kinetic Pathways for Corrosion Reactions	University of Chicago
Experimental and Theoretical Aspects of Corrosion Detection and Prevention	University of Connecticut
Nondestructive Evaluation of Corrosion-Damaged Structures	University of Delaware
Fretting Corrosion in Airframe Riveted and Pinned Connections	Vanderbilt University
Thermal Wave Imaging for NDE of Hidden Corrosion in Aircraft	Wayne State
Inspection Programs	
Ultrasonic Techniques	NWU, Hopkins, UCLA, ISU
Neutron Radiography	MIT
Acoustic Emissions	UCLA
Pulsed Eddy Current	Iowa State University
X-ray	Iowa State University
Electrical Impedance Tomography	University of Delaware
Thermal Infrared Imaging	Wayne State University
Application of Superconducting to Inspection (SQUID)	NWU & Vanderbilt
Speckle Interferometry	State University of NY
Coherent Optical Techniques	Northwestern

TECHNIQUES FOR FLAW DETECTION (RPI 199)

ORIGINATOR:

ANM-100, Rich Yarges

FAA TC/POINT OF CONTACT:

ACD-220, Chris Smith

PURPOSE:

In problem areas identified with ANM, research and develop new, reliable, and cost effective inspection methods for flaw detection in airframes and mechanical components.

BACKGROUND:

- Presence of corrosion and disbonds in fuselage lap joints contributed to the multiple site damage crack link-up in the 1988 Aloha Boeing 737 accident.
- Current inspection techniques can be improved to better detect more subtle and hidden (second layer) flaws.

APPROACH:

- Conduct basic and applied research to demonstrate the feasibility of inspection technologies which improve inspection reliability.
- Emphasize systems which increase resolution capability for multiple site damage, decrease system complexity, expedite lengthy inspections, and/or reduce the need for disassembly.
- Develop inspection systems to a point where the FAA Validation Center can validate and if warranted further develop the systems.

PRODUCTS:

- Report assessing feasibility of improved magneto-optic instrument for second layer corrosion detection.
- Prototype ultrasonic Lamb wave disbond detector.
- Prototypes of pulse-echo thermal wave and dual-band infrared imaging systems for corrosion and disbond detection.
- F ototype laser-ultrasonic system for non-contacting crack detection.
- F ototype self-compensating ultrasonic instrument for second layer crack detection.
- Prototype low-frequency ultrasonic scanner to detect lap joint disbonding and corrosion.
- Prototype robust, noise-insensitive optical interferometer for disbond detection.
- Prototype low and pulsed frequency eddy current instruments to detect second layer corrosion.
- Report assessing ability of acoustic emission to detect damage in aircraft.
- Prototype of backscattering x-ray instrument to detect second layer corrosion.
- Report assessing feasibility of using imbedded fiber optic sensors (smart structures) to detect damage in aircraft.

TECHNIQUES FOR FLAW DETECTION (RPI 199)

CUSTOMER REQUIREMENTS:

- Aircraft Certification offices require the evaluation and development of emerging inspection systems in order to establish performance requirements for inspection system capability and reliability. This information would serve as the basis for initial system certification and alternate means of compliance certification.
- Products will consist of reports documenting feasibility demonstrations and minimum specifications of various emerging and enhanced conventional inspection equipment that have potential applications as alternate means of compliance. Products with successful demonstrations will be handed-off to the FAA Validation Center which will provide additional support data toward an alternate means of compliance approval.

STATUS:

- Thermal Wave Imaging for Corrosion and Disbonds: tested thermal wave technique on the FAA Validation Center's Boeing 737 (**March, 1993**).
- Infrared Imaging for Corrosion and Disbonds: report detailing May 1993 test of dual band infrared technique tested on the FAA Validation Center's Boeing 737 (**August 1993**).
- Ultrasonic Inspection of Bonds: report detailing optimum sound generation of laboratory laser based ultrasonic system (**January 1993**).
- Ultrasonic Inspection of Bonds: report on optimum application of Lamb waves for disbond detection (**March 1993**).
- Ultrasonic Technique for Crack Detection: report of optimum scan parameters for low frequency ultrasonic technique with dripless contact probe (patent pending) (**June 1993**).
- Ultrasonic Technique for Crack Detection: interim report covering development and applicability of self compensating ultrasonic technique.
- Eddy Current for Corrosion Detection: completed development of a pulsed eddy current prototype ready for corrosion testing (**December 1993**).
- Coherent Optical Techniques: Signed a licensing agreement for use of noise suppression techniques for commercial shearography (**August 1993**).
- Radiography for Corrosion Detection: Completed construction of a portable compton backscatter unit for corrosion detection (**September 1993**).

AUTOMATION AND ROBOTICS (RPI 200)

ORIGINATOR:

AFS-300, Fred Sobeck

FAA TC/POINT OF CONTACT:

ACD-220, Dave Galella

PURPOSE:

Develop systems which can reduce inspection time and operator variability during highly repetitive labor intensive inspections.

BACKGROUND:

- As indicated in the NTSB report AAR-89/03 on the Aloha Boeing 737 accident, NTSB cites the need to improve upon the methods presently used to examine very large areas or perform large numbers of repetitive inspections.
- With increasing inspector workloads there is a need to develop systems which can reduce complexity and operator variability during highly repetitive, labor intensive inspections.

APPROACH:

- Utilize signal processing and image enhancement to facilitate inspection and reduce the subjectivity of operator assessments while offering the experienced inspector unrestricted access to the unprocessed (original) inspection data.
- Design and build an automated inspection device for inspection of aircraft lap joints.

PRODUCTS:

- A stand alone automated wheel signal classification system using neural networks. Evaluation of this system in comparison with existing techniques will allow Flight Standards to baseline present system capability and reliability.
- Development of real time image processing software for use in both film-based and real time radiography. Evaluation of this system in comparison with existing radiographic techniques will allow Flight Standards to baseline present radiographic system capability and reliability.
- Prototype automated inspection device to inspect fuselage lap joints. The technical and economic evaluation of this system will offer Flight Standards the ability to anticipate and prepare for the introduction of robotic devices in maintenance facilities.

AUTOMATION AND ROBOTICS (RPI 200)

CUSTOMER REQUIREMENTS:

- Flight Standard offices require the evaluation and development of state of the art systems in order to establish benchmarks and set standards for the performance of the present inspection system capability and reliability. This information would serve as the basis for updating inspection advisory circulars and in exceptional cases rule making.

STATUS:

- The wheel inspection system has been developed and a β-site has been established at Northwest Airlines, Minneapolis for testing. *(The final report on this initiative is forthcoming.) If this system significantly* improves detectability Flight Standards may choose to release an advisory circular on the application of neural nets for inspection system enhancement **(December, 1993)**.
- The real-time image processing system has been demonstrated and shows *potential for a very significant increase in* detectability limits. A β-site for this system has been established with Northwest Airlines in Atlanta. If this system significantly improves detectability Flight Standards may choose to release an advisory circular on the use of image enhancement techniques in x-ray inspections **(December, 1993.**
- A draft interim report on the feasibility and development of a simplified automated nondestructive inspection device has been delivered **(January 1993)**. Further development will occur throughout FY94 and FY95. Final specifications of working prototype will be contained in a report for Flight Standards use as advisory material at **(fourth quarter FY95)**.

VALIDATION CENTER (RPI 201)

ORIGINATOR:

AFS-300, Fred Sobeck

FAA TC/POINT OF CONTACT:

ACD-220, Dick Johnson

PURPOSE:

To provide the necessary environment (hangar, aircraft structures, equipment, and personnel) to demonstrate, validate, and analyze new and emerging technologies and methodologies for inspection, repair, and maintenance of airframes, engines and mechanical components.

To provide the FAA with a procedural tool to perform comprehensive, independent, and quantitative evaluations of new maintenance, inspection, and repair techniques.

BACKGROUND:

- Industry has expressed the need for a maintenance, inspection, and repair "proving ground" which can be used for an independent, quantitative, and systematic assessment of reliability and implementation costs associated with maintenance, inspection, and repair materials, equipment, and procedures.
- An independent facility for realistic evaluations of maintenance, inspection, and repair systems is needed for effective transfer of advanced systems to commercial industry.

APPROACH:

- Define specifications for a maintenance, inspection and repair center to include equipment and representative structural components.
- Develop and establish facility supported analysis and test methodologies.
- Beginning with candidate inspection systems, establish a technology assessment, development, and deployment process.

PRODUCTS:

- A sample library of well characterized aircraft components for use during research, development, and validation efforts. Flight Standards personnel will observe, participate in, and be briefed on the assessment of various technologies applied to aircraft maintenance, inspection and repair.
- Testbed aircraft in a hangar environment to allow realistic demonstration and validation experiments.
- Reports detailing evaluations of maintenance, inspection, and repair procedures and validation studies.

VALIDATION CENTER (RPI 201)

CUSTOMER REQUIREMENTS:

- Flight Standards offices require the evaluation and development of current and emerging maintenance, inspection, and repair systems in order to establish performance requirements (capability, reliability, and cost-effectiveness). This information will serve as the basis for advisory circulars and in exceptional cases rule making.

STATUS:

- A test bed and sample defect library including an entire Boeing 737 aircraft and 300 other pieces of well characterized aircraft components has been established **(1992-1993)**
- Approximately 18 commercial or prototype inspection systems have been demonstrated at the Validation Center. Results of these demonstrations are to be periodically compiled for use by Flight Standards in evaluating these and related inspection systems.

  Assessment of thermal techniques on testbed aircraft **(June 1993)**.

  Assessment of PRI's Magneto Optic Imager on testbed aircraft **(June 1993)**.

  Evaluation of visual inspection aids (**August, 1993**).

  Assessment of D-Sight on testbed aircraft and defect samples (**October, 1993**).

  Evaluation of reverse geometry x-ray on simulated lap splice specimens (**September, 1993**).

  Evaluation of conventional commercial equipment (**April-October, 1993**).

- The Validation Center is working with Chicago Aircraft Certification Office on an assessment of a propeller hub assembly. This hub assembly was rejected on a maintenance check per Hartzell SB165D. This work is in direct support of our Inspection National Resource Specialist. **(October, 1993)**
- The Validation Center continues to work with Northwestern University researchers on cost benefit analyses of potential inspection systems. System range from those with long term potential (Carnegie Mellon Research Institute's robotics) to emerging commercial products (PRI's Magneto Optic Imager) **(on-going)**.
- The Validation Center continues to prepare for a broadened scope of operation by pursuing efforts to establish a capability to pressurize the aircraft for structural integrity and repair studies **(June, 1993)**.

INSPECTION OF ENGINE PARTS (RPI 202)

ORIGINATOR:

ANE-100, Locke Easton

FAA TC/POINT OF CONTACT:

ACD-220, Chris Smith

PURPOSE:

Provide the FAA and engine manufacturers with reliable and cost effective new methods or improvements to mature methods for detecting cracks, inclusions, voids, and other imperfections in titanium and other materials during their production.

Provide reliable and effective new methods for in-service detection of cracks, inclusions, and damage to rotating and non-rotating engine components.

BACKGROUND:

- DC-10 Sioux City accident investigating team has requested research and development to study and develop techniques to reliably detect hard alpha inclusions in titanium turbine engine components.
- New technology exists which may permit continuous monitoring of static engine components to detect over-heating and to prevent burn-through or other unsafe conditions.

APPROACH:

- Develop consortium consisting of Iowa State University and various turbine engine manufacturers.
- Improve titanium defect detection during production by studying effects of surface treatments on inspection response, developing a probability of flaw detection definition practical and acceptable to the industry and FAA, and by researching the cost effectiveness of controlled simulated defects on automated processes.
- Develop an improved methodology for in-service detection of defects in titanium and other engine materials. Preliminary emphasis will be on improving tasks which currently are complex and lengthy (possibly requiring multiple shifts) and those which currently require excessive disassembly and reassembly of components.

PRODUCTS:

- Reliable ultrasonic inspection technique and equipment for titanium defect detection during the production process.
- Inspection technique and procedure development for in-service titanium defect detection. The system will include both manipulation aids (scanners, fan rotators) and signal processing components.
- Development of a universally acceptable probability of flaw detection definition suitable for existing and anticipated aircraft turbine engine components.
- Reports documenting static engine component failures using actuarial data and FAA Service Difficulty Reports data.

INSPECTION OF ENGINE PARTS (RPI 202)

CUSTOMER REQUIREMENTS:

- Aircraft Certification offices require the evaluation and development of current and emerging inspection systems in order to establish performance requirements for inspection system capability and reliability. This need exists for both static and rotating engine components. This information will serve as the basis for general rule making and may assist in the determination life limits for rotating components.

STATUS:

- The Aging Aircraft Program with the assistance of the Center for Aviation Systems Reliability at Iowa State has established a comprehensive program plan that addresses inspection reliability issues in both production and in-service inspection. Issues regarding the industry-wide application of program results are being assessed up-front with the Consortium members (**June, 1993**).
- Titanium hard alpha sample requirements have been defined and material acquisition has begun (**October, 1993**).
- The framework for a probability of flaw detection methodology has been developed which is acceptable to all Consortium members. The adoption of a standardized methodology will be a major asset in the evaluation of existing and emerging inspection systems (**December, 1993**).

VISUAL INSPECTION (RPI 204)

ORIGINATOR:

AFS-300, Fred Sobeck

FAA TC/POINT OF CONTACT:

ACD-220, Dave Galella

PURPOSE:

To determine the adequacy or need for improvement in the reliability of visual inspection tasks by quantitatively determining the probability of detection and other performance characteristics.

To determine the most significant system, human, and environmental factors effecting the reliability of various visual inspection tasks.

To develop visual aids with high potential for cost-effective improvement to the visual inspection process.

BACKGROUND:

- Non-directed inspections are the first line of defense in accident prevention. Flaws detected during non-directed inspection are often the impetus for development of preemptive directed inspection programs.
- Manufacturers and operators prefer to use visual or aided visual inspections whenever possible. Enhancement of procedures and visual aids will ensure the reliability of these visual inspections.

APPROACH:

- Determine the efficacy of select non-directed inspection tasks and develop a strategy for improving the probability of flaw detection.
- Develop visual inspection descriptors intended primarily for use by FAA inspectors as guidelines for monitoring operators and repair facilities.
- Validate performance enhancements of system aids to visual inspection such D-Sight and moiré imaging.
- Develop supporting material for a visual inspection advisory circular on techniques, practice and equipment.

PRODUCTS:

- An integrated database of current visual inspection data consisting of theoretical, empirical, and actual inspection data allowing Flight Standards to perform hypothesis testing for different inspection scenarios.
- A comparative analysis of current visual inspection aids for detection of corrosion, disbonds, cracks, and discrete damage.
- Feasibility studies for current and emerging visual enhancement technologies with respect to cost economics, practicality in aircraft environment, human factors, and reliability.

VISUAL INSPECTION (RPI 204)

CUSTOMER REQUIREMENTS:

- Flight Standards offices require the evaluation of aided and unaided visual inspection in order to assess the efficacy of current directed and non-directed visual inspections. This information would serve as the basis for inspection advisory circulars and rule making which specify the human and environmental conditions and visual aids necessary to perform adequate inspection.

STATUS:

- Physical Research Inc.'s Magneto Optic Imager has been evaluated locally at the Validation Center's hanger (**June, 1993**) and in the field as part of the Eddy Current Inspection Reliability Experiment (**March - August, 1993**).
- In a cooperative effort with the Canadian airworthiness authorities and Diffracto, LTD, a commercial grade prototype D-Sight system has been developed. The prototype was recently evaluated at the Validation Center (**October, 1993**).
- The Validation Center has submitted a work plan for pursuing a visual inspection reliability analysis program. This plan is currently under review (**August, 1993**).
- The Validation Center has identified two areas of visual inspection enhancement where technology development or implementation would result in significant improvements to inspection efficiency and reliability. These areas are local illumination using portable light sources and the integration of heads-up displays in certain inspection systems. The Validation Center has identified vendors of improved flashlights and is currently evaluating their products. The Validation Center was responsible for facilitating the interaction of heads-up display manufacturers with PRI, the manufacturer of the Magneto-Optic Imager.
- Visual training activities have been transitioned to RPI 196, Training and Information Dissemination (**October, 1993**).
- The Center for Aviation Systems Reliability has delivered a technical report on available visual training programs. This program has also been transitioned to RPI 196.

INSPECTION RELIABILITY (RPI 205)

ORIGINATOR:

AFS-300, Fred Sobeck

FAA TC/POINT OF CONTACT:

ACD-220, Chris Smith

PURPOSE:

To determine the adequacy or need for improvement in the reliability of inspection tasks by quantitatively determining the probability of detection and other performance characteristics.

BACKGROUND:

- Aircraft manufacturers and operators have expressed interest in the FAA determining the reliability of various inspection procedures.
- NTSB report AAR-89/03 on the Aloha Boeing 737 accident cites the need to improve reliability of long, repetitive inspection tasks.

APPROACH:

- Estimate probability of flaw detection curves for non-directed inspections from analysis of actual maintenance data.
- Review manufacturers' inspection databases to determine visual inspection probability of flaw detection.
- Conduct field eddy current inspection experiment to generate reliability data incorporating human and environmental factors.
- Provide quantitative reliability data on specific inspection tasks.

PRODUCTS:

- An integrated database of raw data consisting of theoretical , empirical, and actual inspection data allowing Flight Standards to perform hypothesis testing for different inspection scenarios.
- A collection of database analysis tools for establishing self-consistent reliability measures from the integrated database of flaw detection data.
- A periodically updated compendium of reliability data and analysis of that data. Updates of this document will include collection of data and hypothesis testing for inspection systems selected by Flight Standards for analysis.
- A technical report detailing recommended procedures for aircraft inspection reliability analysis.

INSPECTION RELIABILITY (RPI 205)

CUSTOMER REQUIREMENTS:

- Flight Standards offices require the evaluation of current and emerging nondestructive inspection systems in order to assess the efficacy of current inspections. Flight Standards offices also require the archival of field inspection data in order to perform analyses of inspection systems operating with human and environmental parameters exceeding the anticipated range. This information would serve as the basis for inspection advisory circulars and rule making which specify the human and environmental conditions and equipment standards necessary to perform adequate inspection.
- In order to assure a uniform level of safety at all maintenance and inspection facilities, Flight Standards requires that analysis techniques used to evaluate inspection reliability produce comparable results. The set of inspection reliability analysis techniques employed by the FAA must be self-consistent.

STATUS OF PRODUCT DELIVERABLES:

- Work on the analysis of non-directed inspection reliability has resulted in the internal release of a feasibility study with rough visual probability of flaw detection curves (**January, 1993**), and a report detailing the methodology for probability of flaw detection estimation from maintenance data (**October, 1993**).
- Elements of the reliability database have been generated and collected at the FAA Validation Center. The most significant subset of this data is the eddy current inspection reliability data collected at 9 inspection facilities. Because this data is very complete its format will be used as a template for the archival of other data. (**data release presently under negotiation with Flight Standards and Aircraft Certification**).
- Specific recommendations from the eddy current inspection reliability experiment are forthcoming. (**The final report for this activity will be available in April of 1994**).
- Probability of detection methodologies have been selected and developed for the analysis of data from the eddy current inspection reliability program. (**Inspection Reliability at Airline Maintenance Facilities, Volumes I & II, March, May, 1993**).
- The Center for Aviation Systems Reliability has developed an X-ray simulator which helps Level III inspectors and inspection engineers develop and validate inspection procedures. McDonnell Douglas has already worked with this tool to determine the feasibility of x-ray for a real bulkhead inspection on the DC-9 (**March, 1993**).
- The Center for Aviation Systems Reliability has developed a standardization tool for eddy current probes. Testing of this tool at Northwest Airlines resulted in the identification of several bad probes (**March, 1993**).
- Program personnel have assisted PHL Flight Standards personnel in the evaluation of a candidate repair facility proposing the use of laser shearography for detection of fuselage disbonding (**December, 1993**).

Text of Requirements Document

Activities within each RPI are selected, rated, and supported based on their contribution to the alleviation of aircraft inspection problems defined in a periodically updated assessment of priorities. The RPIs themselves contain a description of these priorities but no description of the mechanism for reassessment of these priorities. This document is not intended to be redundant with the RPIs: Its purpose is to provide a comprehensive framework under which Program priorities are developed and evolved.

RPI 199 - Technologies for Flaw Detection

Research Objective(s)

The objective of this research project is to develop improved inspection technologies to address specific aging airframe inspection problems. Cost effective inspection methods employing advanced traditional technologies, emerging technologies, or combinations of technologies will be investigated for their ability to accurately and reliably detect cracks, disbonds, and corrosion damage.

Approach

Activities shall be identified first by the application (as opposed to technique). The present priority remains the detection of cracks indicating the onset of MSD in fuselage lapsplices. Other specific priority areas include[1]

> the aircraft pressure vessel (cracks at rivet sites - especially at skin splices/bulkhead web splices, cracks near window and door surround structure, cracks at run out of large doubler, disbonding of aluminum skins, hidden corrosion in skins and stringers).
>
> aircraft wings and empennage structure (wing spar integrity, cracks in cordwise fastener rows, cracks at stringer run out at tank end ribs).
>
> aircraft mechanical components (landing gear and wheels, door hinges and latches, bushings, other)

Within each problem area a *second* level of categorization may be employed to describe the problem's requirement for specificity (or ability to characterize). Because tasks are categorized first by application area not specificity, former projects such as *Large Area Inspection* no longer exist (though their tasks still do). Some critical issues associated with this second level of categorization include:

> determination of the need to distinguish between corrosion and disbond

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[1] Taken from the final report of the Industry Committee on Widespread Fatigue Damage: A Report of the Airworthiness Assurance Working Group Industry Committee on Widespread Fatigue Damage.

determination of the ability to locate multiple flaws over large areas

In order for the specific research to be considered successful, each technology must either (1) demonstrate an improved level of capability and reliability compared to inspection methods currently used for the same application, or (2) demonstrate an equally effective capability and reliability level with a significant improvement in cost effectiveness. Research efforts will generally focus on uncomplicated inspection techniques which will minimize the required structural disassembly and human- and environment-induced variability.

Identification of Problem Areas: Identification of problems will rely heavily on:

requirements identified by activities under RPI 205, Inspection Reliability

requirements identified by the Industry Committee on Widespread Fatigue Damage

requirements identified by the Aging Aircraft Structural Integrity group

expert opinion (sponsors; NRS: Al Broz, Tom Swift; TOGAA; AANWG)

airworthiness directive and service bulletin review

prioritization studies (*e.g.* Benham Bahr's work)

service difficulty reporting review

workshop feedback

Research to develop improved flaw detection technologies will be conducted primarily by universities, including those comprising the FAA Center for Aviation System Reliability (CASR). Testing and optimization of laboratory prototypes and procedures will be conducted on representative test specimens both in the lab and the field. After successful laboratory development, the technologies will be transitioned to the FAA AANC (RPI 201) for further field development and validation efforts.

Description of Work

Airframe General: Certain generic airframe inspection issues should be kept in mind even when examining specific inspection problems. These generic issues include the following:

Dissimilar material stackups and tapering thickness: Searching for flaws in sub-layers is often made more difficult by particular material combinations. by Eddy current (and other electromagnetic techniques) and radiographic inspection methods while capable of inspecting multi-layer structures are very susceptible to the material properties of the inspection article. Unfortunately many material combinations in typical airframes structures such as door and window frames and pressure vessel tearstraps lead to uninspectable substructure. Material combinations such as steel over aluminum and aluminum over titanium are uninspectable using conventional eddy current technologies. The potential of multi-site damage in such structures poses an even greater problem.

Dissimilar materials and material non-homogenates: In most repetitive inspections (such as rivet line inspections) it is generally assumed that materials and are homogeneous and parts with the same function are similar in both geometry and material. One expects, for instance, that skin cladding or plating is of uniform thickness and that rivets performing the same function are of the same type (countersunk or button head) and material. Even if this were the case for a new aircraft - and this is not necessarily so - older aircraft have often been modified or repaired with components of dissimilar geometry and/or material. Button head rivets may be used in place of flat head rivets, steel fasteners may be substituted for aluminum or titanium fasteners, cladding thickness may have been reduced by excessive buffing, and skin thickness may even be reduced by up to 10%.

Such situations call for the integration of inspection *techniques* into inspection *systems* with the flexibility to handle varying geometries and material properties. In addition such systems must adjust automatically or at least signal the inspector that the technique may be inappropriate for the current inspection. Electromagnetic inspection devices for riveted skins should have a flexible probe arrangement and should alert the user to the presence of significant changes in rivet material or skin cladding, thickness, or conductivity.

Inspection of complex geometries: Eddy current and ultrasonic techniques work well in simple, known geometries. As the structure deviates from that simple geometry implementation problems arise. A known taper over the scan area or geometry variations between similar details (*e.g.* non-jig drilled holes) affects the calibration and hence reliability of the inspection. Specific examples geometric complications include:

use of a reflectance probe for skin splices with button-head rivets

detection of cracks in fittings with short hole to edge distances

detection of cracks in non-jig drilled or multiply drilled fastener holes

Airframe Pressure Vessel: The pressure vessel has been identified as the primary problem area. Specific problems are 1) cracks in aluminum skins at rivet sites, 2) disbonding at skin splices, and 3) corrosion between skins or between stringers and skins.

While the onset of multiple site damage is a difficult phenomenon to define, one can reasonably argue that the reliable detection of cracks at rivet sites just prior to their emergence from under the rivet head would make failure from crack link-up very unlikely. Such a capability has other safety and economic ramifications as discussed below.

Because disassembly and replacement of aircraft skins allows the possibility of introducing additional damage during rework, there exists a need to develop technologies to find small enough cracks that less invasive repairs remain possible. Example: Airworthiness Directive 90-06-02 for the Boeing 737-200 allows 5/32 rivets to be oversized to 0.221 and 3/16 rivets to be oversized to 0.257. This allows cracks less than about 30 mils to be repaired by oversizing. Hence, a requirement for a reliable 25-30 mil detection technology exists for both first and second layers.

Because the absence of corrosion products in skin nearing the 10% thinning limit allow the safe operation of the aircraft without skin replacement, there exists a need to develop a technology which clearly determines the presence and extent of corrosion. Development of such technology will allow Flight Standards to specify more precise corrosion and corrosion thinning requirements.

Because corrosion is often initiated from within the aircraft (leaks in lavatories and galleys) corrosion often begins at the longeron-skin, frame-longeron, or other substructure interfaces. Unlike skin-splice interface corrosion, such corrosion is generally not signaled by the skin pillowing or discoloration at the externally visible joint edges. Since inspections requiring disassembly are infrequent and expose the airframe to possible collateral damage, economically preferable external inspection techniques are also preferable from a safety standpoint.

Because disbonding between fuselage skins may alter the load path and result in premature failure at rivet sites, there exists a need to develop a technique to identify (either directly or indirectly) significant load transfer anomalies between skins. A significant anomaly could be considered a disbond area consisting of more than 5% of the rivets in any continuous load transfer path (skin panel).

Because disbonds which extend to the edge of skin splices allow water intrusion and subsequent corrosion, a need exists to be able to detect disbonds which extend to the edge of skin splices.

Wing and Empenage Structure: Problems associated with inspection of wing structure are generally felt to be less significant than those associated with fuselage inspections. Nevertheless some allocation of resources to specific wing inspection problems may be appropriate.

The thickness of wing skins requires low frequencies, but the rivet spacing (3/8 inch) generally precludes the use of large diameter low frequency eddy current probes.

Other hidden flaw problems include situations such as the DC-9 lower wing skin/tee corrosion. Present techniques require the removal of barrel nuts to accomplish the inspection. Northwesten University, however, has demonstrated that there may be an ultrasonic technique with adequate reliability which does not require the removal of the nuts. Cracks in the DC-10 number 2 engine pylon strap/spar may also be inspectable without disassembly by using an ultrasonic technique.

Aircraft Mechanical Components: Primary interest is in the detection of cracks in aircraft wheels. While the Industry Committee on Widespread Fatigue Damage has identified certain hinge and latch mechanisms as possible candidates for multiple site and multiple element damage, these are not considered significant (difficult) inspection problems.

Product(s)

ANM requires the evaluation and development of emerging inspection systems in order to establish performance requirements for inspection system capability and reliability. This information would serve as the basis for initial system certification and alternate means of compliance certification.

The research identified here will produce laboratory and field prototype systems with reports documenting the development and test results of each technology. Pending successful results in the laboratory, technologies will be validated at the FAA AANC and ultimately transferred to industry. The process is divided into 6 stages:

Stage 1: Laboratory Development
Stage 2: Laboratory Prototype
Stage 3: Field Prototype
Stage 4: Validation of Process
Stage 5: Tech Transfer
Stage 6: Commercialization

Table 1 shows the six steps in this validation procedure and the current status of each of the several initiatives in this RPI. Dates in the 'stage' column represent accomplishment or planned accomplishment dates. Highlighted boxes indicate completed stages. This document is not intended to show project slippage, and hence dates are updated each time this document is produced.

activity	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Local Laser-Based Ultrasonics	9/92	9/93	3/94	3/95		
Self Compensating Ultrasonic Instrument	9/91	9/92	12/93	9/94	12/94	
Acoustic Emission of Aircraft Panels	CRDA - observation status only					
Ultrasonic Lamb Wave for Disbonds	3/94	3/95	9/95	9/96		
Thermal Wave Imaging of Bonds	9/91	9/92	3/94	9/94		
Ultrasonic Characterization of Bonds	9/92	9/93	9/94	9/95		
Air Coupled Ultrasonics	12/94	12/95				
Optical Interferometry & Coherent Optics	9/92	9/93	9/94	9/95		
Portable Holography	12/92	6/93	9/94	3/95		
Dual-Band Infrared Imaging	3/93	3/94	9/95	9/96		
Eddy Current Methods for Corrosion	9/92	12/93	6/94	6/95		
Radiographic Methods for Corrosion	12/91	12/92	12/93	9/94		
Magnetic Imaging of Hidden Corrosion	9/93					
Fiber Optics Inspection Research	3/94					

This research will produce an integrated database consisting of theoretical, empirical, and actual inspection data for corrosion, crack, and disbond inspection methods. This database will be used to develop advisory material on crack, disbond, and corrosion inspection methods.

Specific prototype products include:

an improved magneto-optic instrument for second layer corrosion detection

an ultrasonic Lamb wave disbond detector

pulse-echo thermal wave & dual-band infrared systems for corrosion & disbond detection

a laser-ultrasonic system for crack detection

a self-calibrating ultrasonic instrument for crack detection

a low-frequency ultrasonic scanner to detect lap joint disbonding

an optical interferometer for disbond detection

a low and pulsed frequency eddy current instruments to detect second layer corrosion

Reports detailing technology advancement include:

report assessing ability of acoustic emission to detect damage in aircraft

report assessing ability of backscattering x-rays to detect second layer corrosion

report assessing feasibility of using fiber optic sensors to detect damage in aircraft

RPI 202 - Inspection of Engine Parts

Research Objective(s)

The objective of this research project is to provide reliable and cost effective new or improved methods for detecting cracks, inclusions, voids, and other imperfections in titanium and other engine materials. The methods will be used by the FAA and engine manufacturers during part production and by the aircraft engine service organizations during on-wing and shop service.

Approach

Activities shall be categorized first by application (as opposed to technique). In particular the present categories are:

- engine rotating components (fans, compressors, turbines)
- engine static parts (engine mounts, burner cans)

Engine inspection reliability (particularly of titanium parts) has been cited as a high priority in the FAA Titanium Task Report. A common and valid understanding of the response of inspection techniques to engine titanium defects and inclusions and a uniform and consistent approach to detection reliability need to be developed for both production and in-service inspections.

The detection of titanium defects during the production process will be improved by studying the effects of surface treatment on signal response, by defining of POD that is practical and acceptable to both the FAA and industry, and determining the cost effectiveness of controlled simulated defects and automated processes.

An improved method for in-service detection of defects in engine components will be developed with preliminary emphasis on more efficient methods for complex and lengthy tasks (possibly requiring multiple shifts) and those tasks requiring excessive disassembly and reassembly of components.

Identification of Problem Areas: Identification of specific problems will rely heavily on:

- requirements identified by activities under RPI 205, Inspection Reliability,
- expert opinion (sponsors; NRS: Al Broz; TOGAA; AANWG)
- recommendations of the Titanium Components Review Team,
- airworthiness directive and service bulletin review,
- service difficulty reporting review,
- inspection recommendations resulting from Accident/Incident Reports.
- workshop feedback

An engine inspection consortium, which includes major engine manufacturers and the Center for Aviation Systems Reliability (CASR) at Iowa State University, has been formed to study improving the production and in-service detection of titanium defects.

Independently CASR will also study issues related to static engine parts.

Description of Work

engine rotating components: The Titanium Consortium is divided into four working groups:

fundamental studies group

inspection reliability group

ultrasonics group (production inspections)

eddy current group (in-service inspections)

The Titanium Components Review team has identified the following requirements:

The reliable detection during manufacture of 1/64 inch diameter flat bottom hole (FBH) for billet < 5 inches, 2/64 inch diameter FBH for billet <10 inches and 3/64 inch diameter FBH for billet > 10 inches.

The reliable detection of 1/64 inch diameter FBH in all semi-finish-machined disks (sonic shapes).

Replace or supplement in-service fluorescent penetrant inspections with more reliable eddy-current inspections of the most critical (highest stressed) areas, whenever the engine is disassembled sufficiently to afford access to a major rotating part.

engine static components: CASR has initiated an effort to enhance engine burner can inspections by utilizing neural networks in the processing of real-time x-ray data. A β-site for the prototype has been established with Northwest Airlines.

Product(s)

The FAA expects the Consortium to accomplish the following:

The Consortium will develop a definition of the probability of detection (POD) that is practical and acceptable to the FAA and industry and suitable for aircraft engine components.

The Consortium will select and develop reliable inspection technologies for the detection of defects in titanium engine parts during the production process.

The Consortium will develop an inspection system in-service titanium defect detection. The system will include both manipulation aids (scanners, fan rotators) and signal processing components.

The development of new technologies and the evaluation of existing techniques will assist Air Certification in defining performance requirements for inspection system capability and reliability and will be used to establish recommended practices for aircraft engine maintenance inspectors. This information will also serve as the basis for rule-making and may assist in determining life limits for rotating components.

RPI 205 - Inspection Reliability

Research Objective(s)

The most fundamental objective of this RPI is to determine the adequacy or need for improvement in the reliability of inspection tasks by quantitatively determining the probability of detection (POD) and other performance characteristics. More specific objectives include the determination of the most significant system, human, and environmental factors effecting the reliability of various inspection tasks.

Results of reliability assessments will help to identify problem areas to be addressed under RPI 200 and RPI 203.

Approach

Because no single evaluation method can predict the reliability of in-service inspections with great confidence, this program strives to attack the problem from perspectives involving both experimental and analytical techniques. The two perspectives offer analogous capabilities in problem area identification, implementation evaluation, identification and quantification of factors influencing the system, and evaluation of new or unique inspection technologies. More specifically activities fall into one of four mutually exclusive categories:

inspection assessment using maintenance data

inspection assessment using laboratory or computer simulations

inspection assessment using field experiments

development of tools to assess inspection reliability

Identification of Problem Areas: Identification of problem areas will rely heavily on

expert opinion (sponsors; NRS: Al Broz, Tom Swift; TOGAA; AANWG)

airworthiness directive and service bulletin review

Service Difficulty Reporting review

workshop feedback

A preliminary analysis of Service Difficulty Reporting data has help to identify areas of potential concern. While SDR data is not reliable for specific analyses, it does give us a general idea of how often failures occur in various parts of the aircraft. Though entirely inadequate to decide inspection priorities by itself, the following information will be used to help ensure the proper allocation of resources to Aging Aircraft Inspection Issues.

Tables 1 through 4 were created using ATA codes and word searches in the comments field. While SDR data is in cases incomplete and in other cases redundant, and while ATA codes are not always selected with uniform criteria, several general conclusions can be drawn from the table entries. SDR data was restricted to events reported in 1992 and 1993, but, because of some significant delays in reporting, some of the events occurred significantly earlier.

Airframe Cracking and Corrosion: Table 1 shows the number of SDR reports indicating cracks for all reporting aircraft, Boeing 737's, and McDonnell Douglas DC 9's in six airframe structural areas, while Table 2 shows the number of SDR reports indicating corrosion events for the same aircraft and structural area groups.[2]

	fuselage	wings	empenage	doors	nacelles	landing gear
cracks	5247	1451	441	570	247	213
737 cracks	798	68	7	67	2	1
DC9 cracks	791	95	76	122	23	5

Table 1: SDR airframe cracking incidents

	fuselage	wings	empenage	doors	nacelles	landing gear
corrosion	9615	1112	303	195	70	193
737 corrosion	930	56	25	8	0	1
DC9 corrosion	659	124	20	24	1	11

Table 2: SDR airframe cracking incidents

A search for SDRs involving disbonding[3] in the fuselage revealed 183 reports. 25 of these reports also included some mention of corrosion.

It can be inferred from this data that cracking and corrosion are still very significant problems for the airline industry, and that the bulk of such problems are in the pressure vessel. It can also be inferred that while disbonding may be a problem it is probably considered to be an aggravating factor and not the problem itself.

[2] The search for incidents of cracking identified all reports containing any of the words, 'crack', 'cracks', and 'cracking', in the comments field. The search for corrosion incidents identified all reports continuing either of the words, 'corrosion', or 'corroded'. The specific entries for fuselage, wings, empenage, doors, nacelles and landing gear used the following codes:

fuselage:	ATA code 53XX
wings structure:	ATA code 57XX
empenage:	ATA code 55XX
doors:	ATA code 52XX
nacelles/pylons:	ATA code 54XX
landing gear:	ATA code 32XX

[3] Search for disbond identified all reports contain any of the words: 'disbond', 'disbonding', 'disbonded', 'unbond', 'unbonding', or 'unbonded'.

While fleet sizes are not taken into account in the data the proportion of events within a particular model line seems to indicate that both McDonnell Douglas and Boeing Aircraft suffer from the same general problems.

Fuselage Cracking and Corrosion: Table 3 shows the number of SDR reports indicating corrosion for all reporting aircraft, Boeing 737's, and McDonnell Douglas DC 9's in six airframe structural areas, while Table 4 shows the number of SDR reports indicating corrosion events for the same aircraft and fuselage structural area groups.[4]

	frames	bulkheads	longerons	keel beam	floor beams	skins/plates	attachments
cracks	949	360	532	42	270	1048	86
737 cracks	149	42	57	19	64	245	6
DC9 cracks	124	49	142	1	5	212	20

Table 3: SDR fuselage cracking reports

	frames	bulkheads	longerons	keel beam	floor beams	skins/plates	attachments
corrosion	645	149	1495	109	1340	1402	819
737 corrosion	61	2	100	15	306	105	76
DC9 corrosion	91	24	107	15	47	98	71

Table 4: SDR fuselage corrosion reports

From this data it is reasonable to infer that within the fuselage, the skins and their immediate substructure produce the most burdensome crack inspection and repair problems, while longerons and skins and floor beams produce the most burdensome corrosion inspection and repair problems.

[4] The specific entries for fuselage structural areas used the following ATA codes:

frames:	5311
bulkheads:	5312
longerons/stringers:	5313
keels:	5314
floor beams:	5315
skins/plates:	5330
attachments:	534X

Engine Component Cracking and Corrosion: Analysis of SDR data reported in the years 1992 and 1993 shows that there were 305 incidents of cracking in turbine/turboprop engine components, engine attachments, and engine fittings among all reporting aircraft. While this very few in relationship to the number of airframe cracking incidents, the potential for catastrophic failure associated with individual flaws is much greater. Corrosion reports for all aircraft numbered only 68 in this two year period.

Table 5 shows the breakdown of crack locations by component type[5]. There were to few reports to perform a further breakdown by aircraft model, or to infer problem area priority.

all engines	turbine and turboprop	compression section	combustion section	engine exhaust	thrust reverser
305	43	8	3	92	32

Table 5: SDR engine cracking reports

Description of Work

Four areas of primary importance have been identified:

- visual inspections, both directed and non-directed
- long and repetitive manual inspection
- inspections requiring coordination of several individuals or shifts
- inspections requiring stressful or unusual human performance

This initiative currently encompasses three efforts designed to assess inspection reliability. First, reliability of traditional Inspection procedures will be quantified via field experiments on fabricated lap splices at various operator facilities. Secondly, existing fleet maintenance databases will be queried to assess actual in-service reliability. Finally, an analytical approach will be employed to estimate inspection reliability and optimal inspection techniques and parameters. Each of these approaches will serve as a source of data for an integrated inspection reliability database. This database, updated periodically, will serve as a continuing source of input data for reliability analyses. The AANC will coordinate its system evaluation efforts with activities under this RPI.

Product(s)

AFS requires the evaluation of current and emerging nondestructive inspection systems in order to assess the efficacy of current inspections. AFS also requires the archival of field

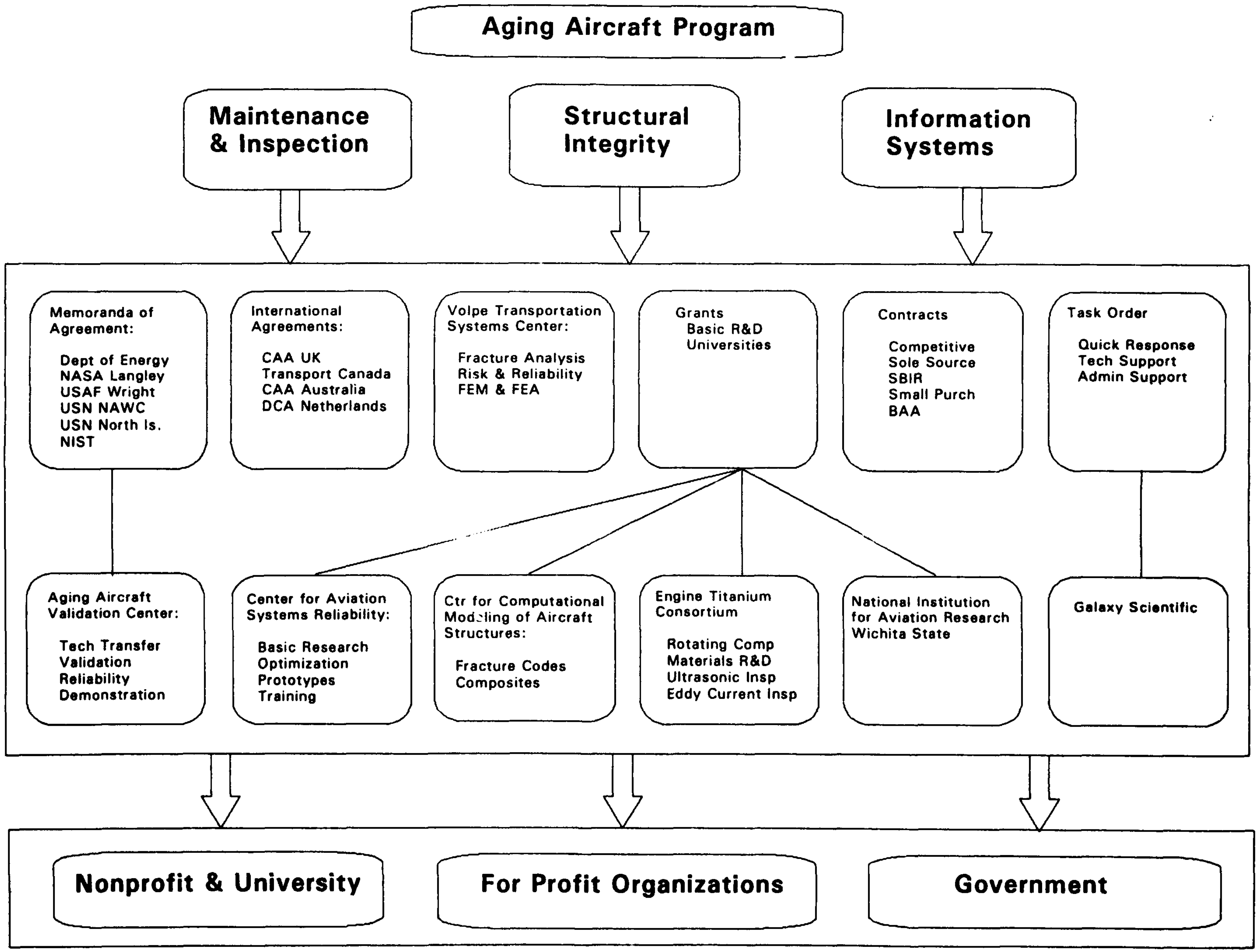
[5] The specific entries for engines and engine components used the following ATA codes:

all engines:	7XXX
turbine and turboprop:	72XX
compression section:	723X
combustion section:	724X
engine exhaust	78XX
thrust reverser	7830

inspection data in order to perform analysis of inspection systems operating with human and environmental parameters exceeding the anticipated range. This information would serve as the basis for inspection advisory circulars and rule making which specify the human and environmental conditions and equipment standards necessary to perform adequate inspection.

In order to assure a uniform level of safety at all maintenance inspection facilities, AFS requires that analysis techniques used to evaluate inspection reliability produce comparable results. The set of inspection reliability analysis techniques employed bye the FAA must be self-consistent.

An integrated database consisting of theoretical and actual inspection data will be developed. The integrated database will enable Flight Standards to simulate different inspection scenarios. A collection of analysis tools to establish reliability measures for the raw data will be developed. Recommended procedures for aircraft inspection reliability analyses will be established. A compendium of reliability data, with an analysis of that data, will be published and periodically updated. Current and emerging inspection technologies will be evaluated to define cost economics, practicality in aircraft environment, human factors, and system reliability. The resulting information will assist Flight Standards in defining inspection performance reliability and will be used to establish recommended practices for aircraft maintenance inspectors. This information will provide guidance in rule-making and in developing Advisory Circulars.


Aging Aircraft Program
Maintenance & Inspection
Structural Integrity
Information Systems
Memoranda of Agreement:
Dept of Energy
NASA Langley
USAF Wright
USN NAWC
USN North Is.
NIST
International Agreements:
CAA UK
Transport Canada
CAA Australia
DCA Netherlands
Volpe Transportation Systems Center:
Fracture Analysis
Risk & Reliability
FEM & FEA
Grants
Basic R&D
Universities
Contracts
Competitive
Sole Source
SBIR
Small Purch
BAA
Task Order
Quick Response
Tech Support
Admin Support
Aging Aircraft Validation Center:
Tech Transfer
Validation
Reliability
Demonstration
Center for Aviation Systems Reliability:
Basic Research
Optimization
Prototypes
Training
Ctr for Computational Modeling of Aircraft Structures:
Fracture Codes
Composites
Engine Titanium Consortium
Rotating Comp
Materials R&D
Ultrasonic Insp
Eddy Current Insp
National Institution for Aviation Research
Wichita State
Galaxy Scientific
Nonprofit & University
For Profit Organizations
Government

FY93-FY94 Contractor Support

199 Techniques for Flaw Detection	
Local Laser-Based Ultrasonics	CASR - Northwestern University
Self Compensating Ultrasonic Instrument	CASR - Northwestern University
Acoustic Emission Evaluation of Aircraft Panels	Grumman Aerospace
Portable Holography	University of New South Wales (Australia
Optical Interferometry	CASR - Northwestern University
Thermal Wave Imaging of Adhesive Bonds	CASR - Wayne State University
Ultrasonic Characterization of Adhesive Bonds	CASR - Iowa State University
Dual-Band Infrared Imaging for Aircraft Inspection	Lawrence Livermore National Labs
Eddy Current Methods for Corrosion Detection	CASR - Iowa State University
Radiographic Methods for Corrosion Inspection	CASR - Northwestern University
Air Coupled Ultrasonics	CASR - Iowa State University
Ultrasonic Lamb Wave Disbond Detection	Pennsylvania State University
Fiber Optics Advanced Inspection Research	North Carolina A&T
200 Inspection Automation and Robotics	
Neural Nets for Signal Classification	CASR - Iowa State University, Northwestern University
Image Processing for Radiographic Inspection	CASR - Iowa State University, Northwestern University
Surface Crawling Robot for Fuselage Inspection	Carnegie Mellon Research Institute
Technology for Robotic Inspection of Aircraft	NIAR - Wichita State University
Simulation of Automated Inspection Devices	DOI - Bureau of Mines
202 Inspection of Engine Parts	
Neural Nets for Engine Inspection	CASR - Iowa State University
Detection of Hard Alpha in Titanium Alloys	transitioned from CASR/ISU to Ti Consortium 3/93
Inspection Reliability	Ti Consortium (CASR/ISU, Garrett, GE, P&W)
Fundamental Studies of Titanium	Ti Consortium (CASR/ISU, Garrett, GE, P&W)
Ultrasonic Inspection During the Production Process	Ti Consortium (CASR/ISU, Garrett, GE, P&W)
Eddy Current Inspection During Engine Service	Ti Consortium (CASR/ISU, Garrett, GE, P&W)

FY93-FY94 Contractor Support (Continued)

204 Visual Inspection	
Visual Inspection Material for Advisory Circular	in-house
Reliability Assessment using Maintenance Data - Visual	in-house
Visual Acuity Survey	National Institute of Standards and Technology
Visual Inspection Probability of Detection Experiment	AANC - Sandia National Laboratories
Enhanced Visual Inspectin Program for Airlines	SBIR - Wilson Composite
Visual Inspection Enhancement Technologies	AANC - Sandia National Labratories
Corrosion Detection using D-Sight	Transport Canada in conjunction with Diffracto, LTD
205 Inspection Reliability	
Inspection Prioritization Methodology	NIAR - Wichita State University
Reliability Assessment using Maintenance Data	in-house
Eddy Current and MOI Reliability Experiment	AANC - Sandia National Labratories
Detection of Subsurface Corrosion using Improved MOI	Physical Research, Inc.
Eddy Current Calibration and Standardization	CASR - Iowa State University
Failure Property Relationships of Adhesive Bonds	CASR - Tuskegee University
Develop Computer Models for Inspection Simulation	CASR - Iowa State University
Coherent Optics Metrology Techniques	AANC in conjunction with New Mexico State University
Application of Models to Specific Inspections	CASR - Iowa State University
Other Activities	
Johns Hopkins Center for Nondestructive Evaluation	Johns Hopkins University
Iowa State Center for Nondestructive Evaluation	Iowa State University

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April 11, 1994

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Dear David:

Thank you for your interest in the Sandia Labs Aging Aircraft Program. The intent of this letter is to provide you with some background information on the Aging Aircraft NDI Validation Center (AANC) and to invite your participation while developing advanced ultrasonic inspection techniques.

The AANC was established by the Federal Aviation Administration Technical Center (FAATC) at Sandia National Laboratories in August 1991. This Center supports the inspection portion of the FAA's National Aging Aircraft Program through validation and reliability projects and through technology development initiatives. To support these goals, the AANC has set up a hangar facility at the Albuquerque International Airport. The NDI Validation Center is intended to replicate a working maintenance environment where human factors which influence inspection reliability can be controlled. It contains test beds for use by private and government sectors in its growing Test Specimen Library.

Attached is a "Customer Preliminary Information Packet" and a "Validation Experiment Planning Packet" which are intended to initiate and aid the experiment planning process. They introduce the AANC to prospective Validation Center users and allow the AANC to acquire information about the user's NDI technique and equipment. The packets contain several questionnaires which help you provide key information to AANC staff. Please return your surveys as soon as possible. You are also invited to make a pre-experiment visit to the Center in order to aid the planning process.

During the course of your interactions with the AANC, you will primarily be dealing with three individuals: the NDI Experiment Coordinator (Craig Jones, 505-845-9063), the NDI Technical Expert (John Gieske, 505-844-6346), and the facility manager (Ken Harmon, 505-843-8722). The NDI Experiment Coordinator will help you plan your AANC experiments and will, in general, strive to maximize the benefit you receive from your time spent here. The NDI Technical Expert will assess the NDI equipment/technique and will provide important customer feedback necessary for continued equipment improvements. **Your visit is scheduled for April 18-20, 1994.** Since almost all of the specimens in our Test Specimen Library reside at the AANC, you can select the appropriate specimens for testing, including the 737 aircraft, when you arrive. You should plan on spending 2 to 5 days at the AANC to allow time for pre- and post-test meetings and planning sessions for possible future visits.

As a developer of aircraft inspection techniques, you are an AANC customer; the AANC seeks to aid your development process through in-house experiments and constructive feedback. All of your inspection results will be archived in the Center's Test Specimen Library Database. This will allow you to make future comparisons if you return to the AANC with an improved product. Thank you again for your interest in the AANC and we look forward to working with you in the development of improved aircraft inspection techniques. If you have any questions please call me at (505)844-6078.

Sincerely,

Dennis Roach

Dennis Roach
AANC Project Engineer

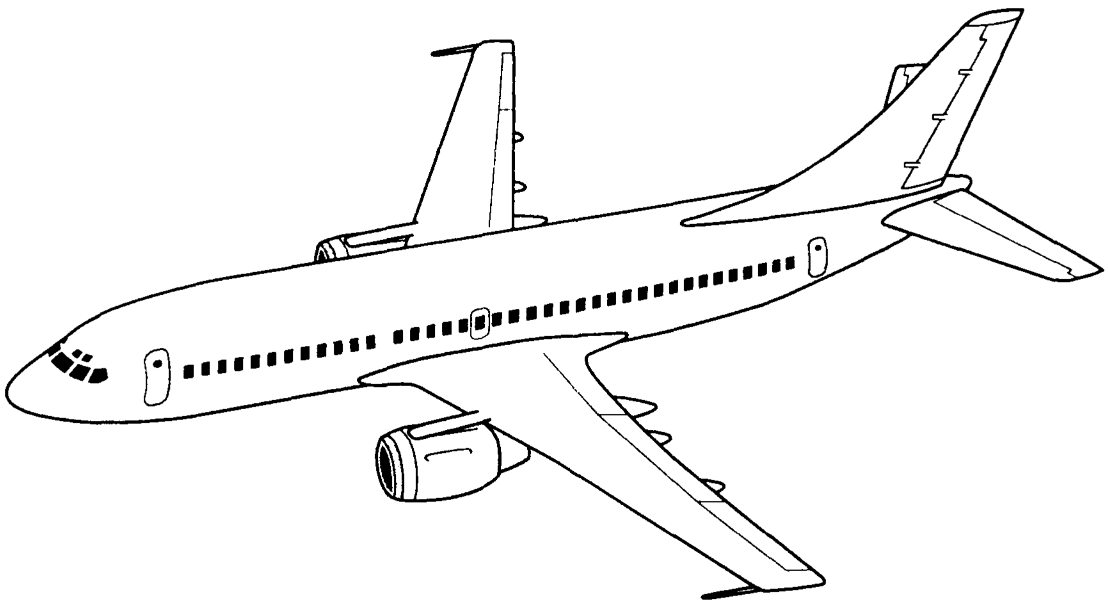
cc:
Pat Walter, AANC
Ken Harmon, AANC
Bill Shurtleff, AANC
Craig Jones, AANC
John Gieske, AANC

Dick Johnson, FAA Technical Center
Chris Smith, FAA Technical Center

Sandia
National
Laboratories

AGING AIRCRAFT

NDI VALIDATION CENTER



Customer Preliminary Information Packet

Prepared By : Dennis Roach
Sandia National Labs
(505)844-6078

AGING AIRCRAFT NDI VALIDATION CENTER (AANC) CUSTOMER PRELIMINARY INFORMATION

BACKGROUND

The AANC was established by the Federal Aviation Administration Technical Center (FAATC) at Sandia National Laboratories in August of 1991. This Center supports the inspection portion of the FAA's National Aging Aircraft Program with the following specific goals :

1. To promote NDI technology development and maturation

2. To help transfer new technology to the hangar floor

3. To validate NDI techniques

4. To assess the reliability of NDI methods.

To support these goals, the AANC has set up a hangar facility at the Albuquerque International Airport. The NDI Validation Center is intended to replicate a working maintenance environment which incorporates both physical inspection difficulties as well as the human factors which influence inspection reliability. A **"Validation Process"**, which allows for an independent and systematic assessment of NDI processes, and a **"Test Specimen Library"**, which consists of an array of full-scale, representative sections of airframe and engine structures with natural or engineered defects, are two key elements in the Center's activities.

A more detailed description of the AANC and its current activities is provided in the attached paper. *Also enclosed in this initial information packet is a questionnaire requesting information from you. In order to maximize the benefits which you may receive from your interactions with the AANC, the questionnaire prompts you for information which will allow the AANC to begin planning your Validation Center experiment(s).*

HOW THE PROCESS WORKS - INTERACTING WITH THE CUSTOMER

As a developer of aircraft inspection techniques, you are an AANC customer. It is obvious from the Center goals cited above that our charter is to aid your development process through in-house experiments and constructive feedback. The status of your NDI process may currently be anywhere from initial conceptual ideas to a turnkey device which is field implementable and ready to market. The AANC actively works with researchers or companies at either end of the development spectrum. We utilize discussions with the FAA, the manufacturers, and the airlines to allow us to optimally utilize our center and to better serve your individual needs. You are welcome to make a preview visit to the AANC if you feel that it would help you plan more productive experiments.

Aside from experiments on mature technology which attempt to quantify the reliability of NDI techniques through the use of "blind" defect specimens and beta site testing, most of the Center validation activities are not intended to "grade" a customer's equipment or technique. It is hoped that your use of the Center will be viewed as an opportunity to improve your system through a better understanding of aviation industry needs in general and specific inspection requirements in particular. The AANC recognizes that a facility user may visit the center a number of times as they mature their product or technique.

Please also keep in mind that you will be receiving additional information as the formal experiment planning takes place in the near future. At that time, you will receive follow-on information about the Test Specimen Library, the Validation Process, hangar amenities and operations, and general information addressing what you should expect from your experience at the AANC.

A PROGRAM TO VALIDATE INSPECTION TECHNOLOGY FOR AGING AIRCRAFT

Patrick L. Walter
Sandia National Laboratories
Albuquerque, NM 87185

Abstract

This paper provides an overview of a program established at Sandia National Laboratories by the Federal Aviation Administration (FAA) to validate nondestructive inspection (NDI) processes for application to aging aircraft. The paper describes an NDI Validation Center, an evolving library of specimens with typical defects, a validation process, ongoing related field experimentation, and current and future work activities.

Introduction

The Aging Aircraft NDI Validation Center (AANC) was established by the Federal Aviation Administration Technical Center (FAATC) at Sandia National Laboratories (SNL) in August of 1991. This Center supports the Inspection portion of the FAA's National Aging Aircraft Program. This national program was mandated by Congress through the 1988 Aviation Safety Act. While the AANC's funding source is the FAA, its ultimate customers include the airframe and engine manufacturers, airlines, and third party maintenance facilities.

The goal of the AANC is to provide independent validation of technologies intended to enhance the structural inspection of aging commuter and transport aircraft. The existing oversupply of passenger capacity and poor airline earnings (1), coupled with defense cutbacks, indicate that technologies validated by the AANC should also attempt to contribute to the financial health of the aviation industry. The deliverables from the AANC's validation activities will be an assessment of the reliability of proposed inspection technologies as well as analyses of the cost benefits to be derived from their implementation.

Center Key Elements and Status

<u>NDI Validation Center</u>-A ribbon cutting ceremony which officially opened the NDI Validation Center was hosted by SNL on February 10, 1993, at the request of the FAATC. The Center is housed in a hangar on the west side of Albuquerque International Airport. This site has close proximity to SNL, ease of access for Center users, and access to airport repair and maintenance facilities. The Center contains 16,875 square feet of aircraft storage space, 7,762 square feet of office and storage space, and 99,988 square feet of outdoor pad space. The Center is intended to replicate a working maintenance environment where human factors which influence inspection reliability can be controlled.

It contains test beds for use by private and government sectors in its growing Sample Defect Library .

Sample Defect Library-This Library contains samples of the major types of damage encountered in aging aircraft for use in validating NDI processes. It presently contains over 100 examples of aircraft repairs; panel, skin and frames sections; and other structural elements. The Sample Defect Library contains representative examples of corrosion, disbonds, and fretting, as well as first and second layer fatigue cracks. A B737-200 with 46,358 cycles, a nonworking JT8D engine, and its complete maintenance records resides in the Center's Library. By using an entire aircraft, the AANC can assess human factor issues such as accessability (e.g., on wing inspection), hangar environmental issues, and inspector-aircraft-NDI equipment interactions. The aircraft can also be used to assess NDI techniques which require fuselage pressurization. Figure 1 illustrates the aircraft/hangar environment. Currently, large sections of DC9 fuselage structure are also being acquired.

Validation Process- The Validation Process (3) consists of an independent, quantitative, and systematic assessment of both the reliability and the implementation costs of an NDI process. An NDI process is defined as the NDI systems and procedures used for inspection; as well as the NDI equipment operator, inspection environment, and the object being inspected. The phases of the Validation Process are Phase 1. Conceptual, Phase 2. Preliminary design, Phase 3. Final design, and Phase 4. Field implementation. Validation activities in Phase 1 are comprised of identification of the interrogated component, flaw, and material type; laboratory verification; initial capability assessment; and initial equipment cost assessments. Phase 2 activities involve laboratory tests, identification and enumeration of preliminary NDI procedures, inspector requirements, and facility requirements. Phase 3 includes assessment of factors affecting reliability, demonstration of feasibility through "blind" procedures, acquisition of inspection time data, and early field trials. Phase 4 involves preparation of validation samples, finalization of procedures, field trials with independent inspectors, field trials with potential users, assessment of inspector training needs, and Beta-site testing.

The AANC becomes progressively more involved through Phases 2, 3, and 4 of the Validation Process. To the extent possible, the environment and conditions affecting inspection will be incorporated into the validation activities that take place in the AANC's Validation Center. If necessary, field trials and experiments to provide input into the reliability and implementation cost assessments will be coordinated at operating airline facilities. The AANC may train airline personnel in the use of a given NDI process and loan them equipment for additional feedback. The first NDI instrument to enter the Validation Process is the Magneto-Optic/Eddy Current Imager (MOI) manufactured by Physical Research, Inc. This instrument uses a magneto-optic sensor to directly view the magnetic field images associated with cracks on the surface of a material.

Field Experimentation-A Principal Structural Element (PSE) is defined as that part of structure whose failure could lead to the loss of the aircraft. All transport aircraft and some commuters are now designed to Damage Tolerance Analysis (DTA) requirements. DTA is the combination of slow crack growth analysis, residual strength calculations, and NDI procedures (2). FAR 25.571 "Airplane Damage Tolerance Requirements" mandates design requirements for transport aircraft and Figure 2 illustrates the ingredients that make up DTA. Probability of Detection (POD), included in Figure 2 as a function of flaw size, is the fraction of flaws of nominal size, "a", that are expected to be detected in a given inspection. The POD associated with a given NDI process is a key ingredient in setting the inspection interval for a PSE. Airframe manufacturers' determine the POD at their facility for the NDI process they specify to inspect a given PSE. They then apply conservatism (4) to account for differences between the POD they determine and what they expect to exist in the environment of a field maintenance facility. The question unanswered is: what is the actual POD associated with an NDI process at the field maintenance facility?

At the FAATC's request, the AANC designed and is currently implementing an experiment to quantitatively assess the reliability (POD) of high-frequency eddy current inspections of lap splice joints in airline maintenance and inspection facilities. Human factor issues which can degrade inspector performance are encompassed in this experiment (5,6). Specific factors to be studied within the experiment plan include off-angle cracks, unpainted versus painted surfaces, variation of reference standards, accessibility of the task, time into task (boredom), work shifts, and differences in specimen definition. Data will be collected during the experiment on facility conditions such as lighting, noise level, and inspector training and recency of experience. Figure 3 shows the experimental setup which includes approximately 76 feet of lap splice. This experiment is traveling to nine maintenance facilities, three of which are third party (not directly associated with an airline). A human factors expert and an NDI technician are traveling with the experiment. Science Applications International Corporation (SAIC) and AEA Technology, Harwell (UK) participated with SNL in the experiment design. SAIC is fielding the experiment for SNL.

Previously mentioned was that the MOI was the first instrument to enter the Validation Process. The MOI was originally designed to inspect for surface cracks at rivet sites on aircraft skin as a competitive technology to high-frequency eddy current probes. Incorporation of the MOI into this field experiment allows its reliability to be assessed and directly compared to PODs determined for the high-frequency eddy current inspections. The Northwestern University Transportation Center (NUTC) is performing a cost benefit analysis of the MOI.

Current Work Activities-The POD of Eddy Current Lap Splice Experiment has traveled to five maintenance facilities thus far: American Airlines, Dalfort Aviation, Aloha Airlines, Tramco, and Alaska Airlines. The MOI was integrated into this experiment during stops at American and Dalfort. Four more facilities will take part in the experiment through August of 1993.

The FAATC has funded NDI initiatives at Penn State, Wichita State, Carnegie Mellon, and Johns Hopkins Universities; Grumman Aerospace; and Transport Canada. In addition, its other principal center, Center for Aviation Systems Reliability (CASR: Iowa State, Northwestern, and Wayne State Universities), has many NDI initiatives in progress. Most of these initiatives are in Phase 2 of the Validation Process and will soon be reaching the AANC for demonstrations or early field trials. Wayne State University recently completed one week of demonstrations at the AANC using Thermal Wave Imaging on the B737 aircraft. This imaging is a broad area technique to locate corrosion and disbonds. In addition, the AANC is surveying commercially available manual scanners for eddy current and ultrasonics aircraft inspection as well as commercially available visual inspection aids (e. g., light sources, shadow Moire, structured light). New Mexico State University also is working within the AANC on shearography aided inspection. This laser based inspection technique will be able to map whole strain fields for applications such as quantifying bond degradation in repair applications.

Work is also continuing on acquiring additional blind samples for the Sample Defect Library of the Center. A data base is being established for this Library to electronically catalogue specimen histories and to store inspection results.

Future Work Activities-Experience gained from field experimentation will identify those key human factor elements to replicate in the Validation Center. This will enable a more cost effective assessment of the reliability of NDI processes. A program in visual experimentation will also be initiated. In visual inspection, the human being is the equivalent of the NDI instrument. It is difficult to assign a quantitative reliability to visual flaw inspection. Flaws are detected by many clues such as sight ("smoking rivets"), touch (rough surface), and smell (leaking fuel vapors). Nevertheless, comparative visual inspection experimentation may be performed to assess effects such as directivity, stand-off distance, and inspection aids.

A program will be initiated to baseline the condition of the AANC's B737 aircraft. Dependent on findings, engineered flaws may be placed in the airframe structure against which to assess NDI processes. The Sample Defect Library will continue to be expanded as will its database to accomodate electronic media input as well as to implement data fusion for comparison among multiple inspection techniques. Techniques will be developed to pressurize the B737 to operating cabin levels. This will enable validation of processes associated with NDI techniques such as shearography and acoustic emission which are dependent on a pressurized aircraft. As the funded NDI initiatives within the FAATC's program continue to mature, the AANC will become increasingly involved with field trials and Beta-site testing to interface the FAA's program to the civil aviation industry.

Conclusion

This paper has described the Aging Aircraft NDI Valiation Center established at Sandia National Laboratories by the Federal Aviation Administration Technical Center. The AANC and its Sample Defect Library, integrated into a defined Validation Process, are allowing the reliability and cost effectiveness of NDI processes to be assessed. The

AANC is also conducting a POD experiment which will provide a quantitative assessment of the reliability of existing high frequency eddy current lap splice inspections in airline maintenance facilities. This field experiment will help identify which key human factors to replicate within the Center to provide a more economical and faster assessment of field reliability. A program in visual experimentation will soon be initiated. The AANC will become increasingly involved with field trials and Beta site testing to best interface the FAA's program to the civil aviation industry.

*This work is supported by the FAA Technical Center, Atlantic City International Airport, New Jersey.

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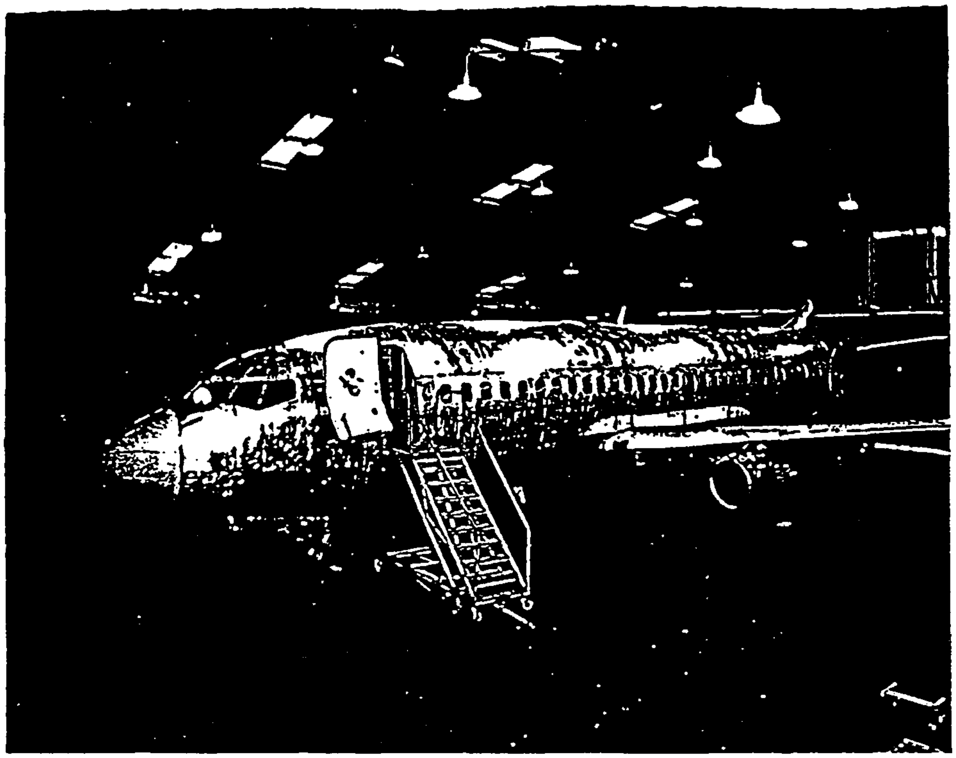
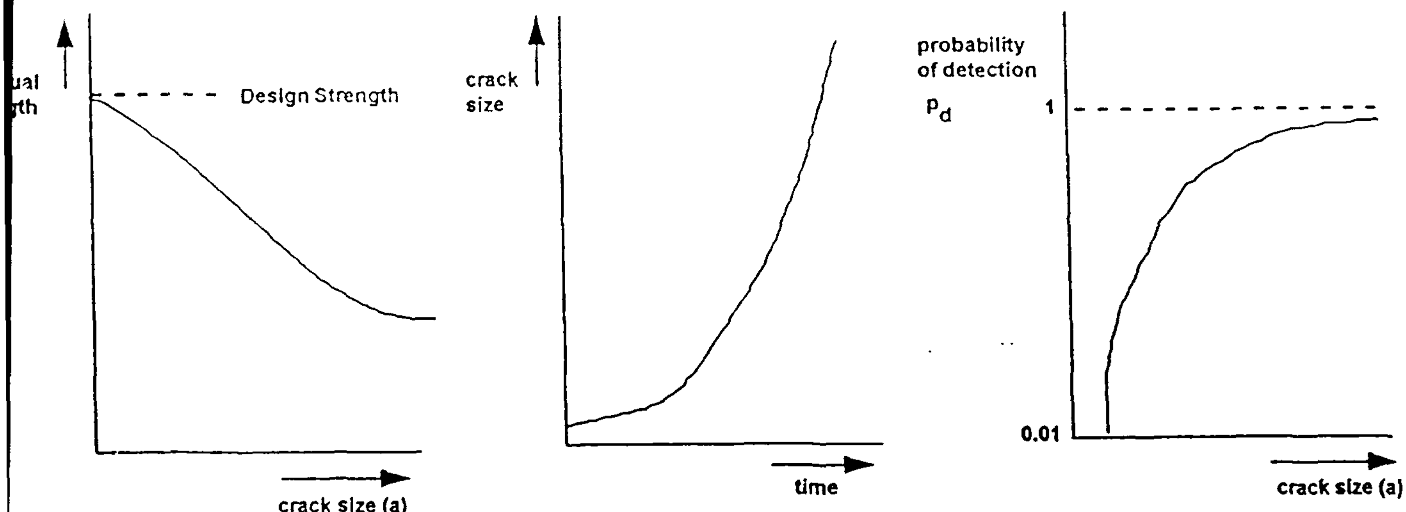


Figure 1. Aging Aircraft Test Specimen in Validation Center



a. Residual strength in a principal structural element

b. Crack growth model

c. Probability of detection for a given inspection technique

Figure 2. Components of Damage Tolerance Analysis

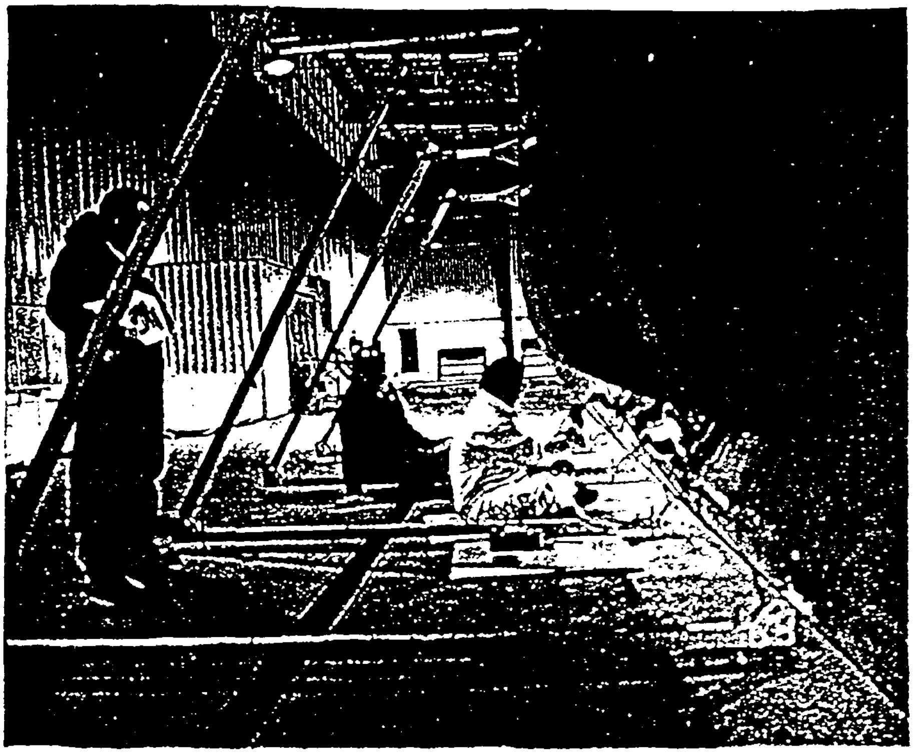


Figure 3. POD of Eddy Current Lap Splice Experiment

NDI VALIDATION CENTER CUSTOMER SURVEY: AANC PRELIMINARY PLANNING INFORMATION

Please answer all questions as thoroughly as possible and continue answers on separate sheets if necessary. The following questions will be used to assess your needs and to allow the AANC to begin initial experiment planning.

1. Name your technique and describe how it works (attach any pertinent supporting material: copies of publications, background information, or other descriptions of method).

2. Is this a derivative of an existing technique ? _______. If yes, what new aspects have you added ?

3. What type and size of defects will this technique detect ? (e.g. corrosion, debonds, 1st and/or 2nd layer cracks)

4. If you have specific information, discuss the aircraft inspection requirements that your technique can address (e.g. Airworthiness Directives, Service Bulletins or Supplemental Structural Inspection Documents).

5. Who referred you to the AANC ? Name - ____________________

Affiliation - ____________________

Phone - ____________________

List any other significant contacts you've made with the aviation industry (e.g. airlines, airframe or engine manufacturers) concerning your NDI technique. These may be locations where you have performed field trials or demos.

6. If you have done any external testing of your equipment/technique (e.g. field tests at airlines, participation in NDI studies), list and explain the nature of each test.

7. Which of the following best describes the stage of development (status) of your equipment/technique? *(Circle one)*

   A. Conceptual - verification of basic concept or usage
   B. Preliminary design phase - validation of prototype and/or inspection requirements with continued improvements in mind
   C. Design Completion Cycle - reliability study with blind experiments; quantitative assessment of technique occurs here
   D. Field Implementation - final optimization of procedures and equipment; AANC acts as a Beta Site tester

8. What do you expect to gain from your tests at the AANC ? *(Circle all that apply)*

   A. Access to defect samples and aircraft testbed to improve product (e.g. assess basic staging requirements and field environment affects)
   B. Access to well-characterized blind samples to assess reliability or sensitivity
   C. Exercise a prototype and develop operation procedures
   D. Assess final requirements for use by industry - independent testing, training needs, finalize procedures
   E. Other (add specific comments to clarify) ______________________

   ____

9. What role would you like the AANC to play in your tests ? *(Circle all that apply)*
   A. Provide facility and test specimens
   B. Provide guidance regarding industry needs, procedures, inspection requirements or other
   C. AANC personnel will act as independent user
   D. AANC performs trained observations and qualitative assessments
   F. Formal Validation Process - reliability, cost analysis, blind samples, field trials, Beta Site testing
   G. Other ____

   ____

10. Provide all relevant information (e.g. photos and schematics of proposed equipment set-up) which will allow the AANC to assess facility requirements, test limitations and safety issues. This information is key to making your visit successful.

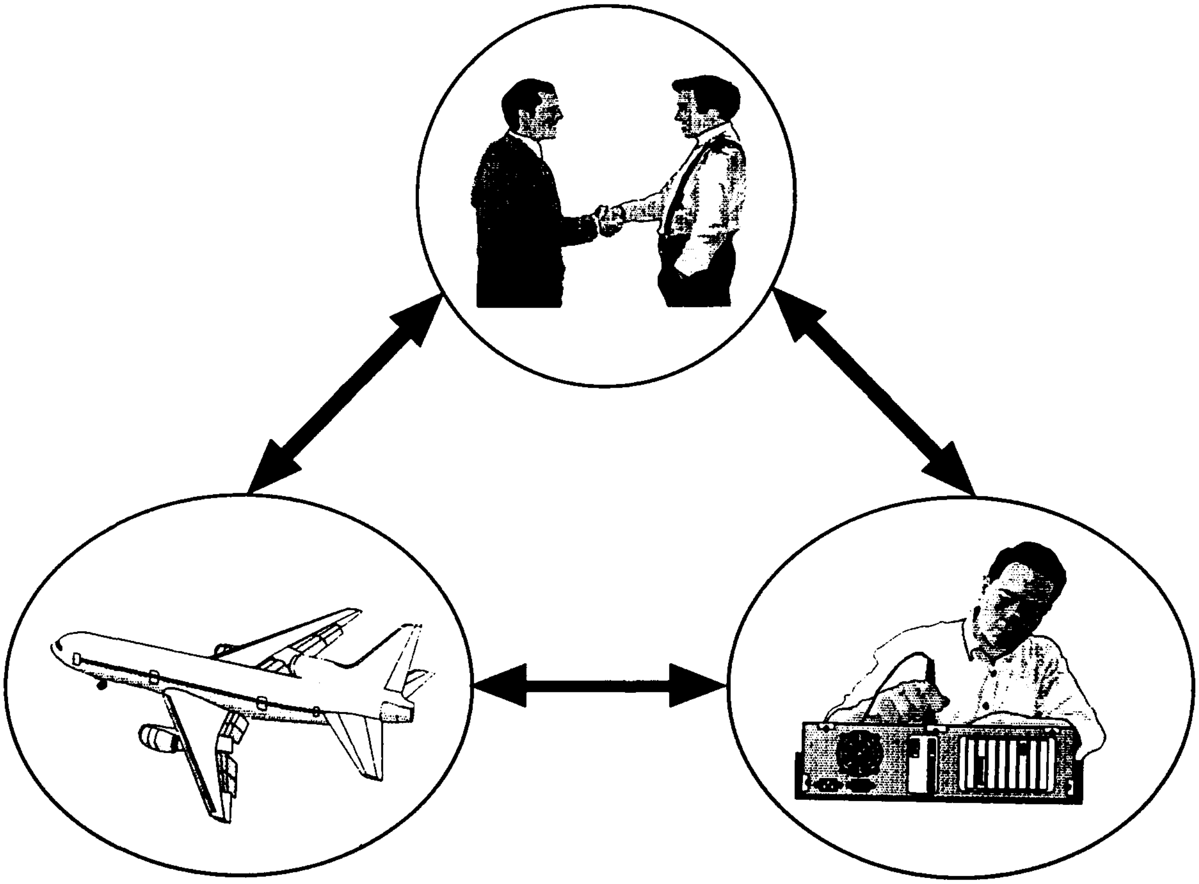
Please return the survey to your Experiment Coordinator at:

Sandia National Labs
Aging Aircraft NDI Validation Center
P.O. Box 5800
MS-0616
Albuquerque, NM 87185-0616

Sandia National Laboratories

AGING AIRCRAFT

NDI VALIDATION CENTER



Validation Experiment Planning Packet

Prepared by : Dennis Roach
Sandia National Labs
(505)844-6078

Aging Aircraft NDI Validation Center (AANC) Validation Experiment Planning Packet

Thank you for your interest in conducting NDI experiments in the FAA/AANC NDI Validation Center. This is the second, and more detailed, of two information packets which you have received from the AANC. You should have already received the "Customer Preliminary Information Packet" and have responded to the general customer survey. The purpose of this packet is to provide you with more detailed information regarding the FAA/AANC NDI Validation Center and to facilitate formal experiment planning prior to your arrival at the Center.

After reviewing this information you should contact your Experiment Coordinator to discuss the specifics of your activities at the Center. The ultimate goals of this information exchange are: 1) to accommodate your immediate needs of developing a test plan, and 2) to provide you with as much information as possible regarding the FAA's aging aircraft NDI development program. As you plan your upcoming visit to the Center please keep in mind that you do not have to demonstrate a perfected technique; the status of your NDI process may currently be anywhere from initial conceptual ideas to a turnkey device which is field implementable and ready to market. The AANC actively works with researchers or companies at either end of the development spectrum. Specific experiment requirements and restrictions will not be imposed on you by the AANC unless you are participating in formal NDI validation exercises involving blind flaw samples and quantitative evaluations. These formal validation processes are carried out on late Phase 3 and Phase 4 NDI techniques (see Section 2: "NDI Validation Process"). Finally, keep in mind that you may visit the center a number of times as you mature your product or technique. We look forward to serving your needs throughout your interaction with the AANC.

CONTENTS

1. BACKGROUND

The AANC was established by the Federal Aviation Administration Technical Center (FAATC) at Sandia National Laboratories in August of 1991. This Center supports the inspection portion of the FAA's National Aging Aircraft Program with the following specific goals :

1. To promote NDI technology development and maturation

2. To validate NDI techniques by:
   A. assessing their reliability
   B. assessing their cost effectiveness.

3. To help transfer new technology to the hangar floor

To support these goals, the AANC set up a hangar facility at the Albuquerque International Airport and began operations in the hangar in February 1993. The NDI Validation Center is intended to replicate a working maintenance environment which incorporates both physical inspection difficulties as well as the human factors which influence inspection reliability. A **"Validation Process"**, which allows for an independent and systematic assessment of NDI processes, and a **"AANC Test Specimen Library"**, which consists of an array of full-scale, representative sections of airframe and engine structures with natural or engineered defects, are two key elements in the Center's activities.

2. NDI VALIDATION PROCESS

The reliability and efficiency of airframe inspection operations are key to ensuring the continued air worthiness of the world's airline fleets. While new inspection technologies can improve reliability and efficiency, to gain maximum benefit from the program, the results must be objectively assessed and integrated into optimized inspection methodologies. The process discussed below, and described in detail in Reference [1], provides a definitive process for inspection validation and is the foundation for all NDI experiments in the Center. Therefore, your understanding of this process will allow you to work with the AANC in designing an experiment plan with maximum benefits to you. A copy of Ref. [1] is available upon request.

Reference [1], "The Role of the Aging Aircraft NDI Validation Center in the FAA Validation Process," relates the NDI development process to important characteristics such as reliability and implementation costs. It also details the sequential development phases and the validation activities which accompany each of these stages. The four development phases cited are: 1) Conceptual, 2) Preliminary Design, 3) Final Design, and 4) Field Implementation. Inspection techniques which utilize the AANC will be in different stages of development. Thus, the associated validation testing will range from bench top experiments carried out in the light labs to tests which utilize the airplane test bed or other full-scale validation assemblies.

In order to define and organize the critical activities that are necessary in a validation process, the general validation tasks associated with a given development phase are summarized in Table I.

TABLE I: VALIDATION ACTIVITIES	
Development Phase	**Validation Activities**
1. Conceptual	• Identify 1. interrogated component and material type 2. flaw types and inspection requirements 3. inspector requirements 4. critical elements • Verify in laboratory • Assess inherent capabilities (theoretical) • Estimate (order of magnitude) capital equipment and material needs for routine inspections
2. Preliminary Design	• Test in laboratory on specified test samples • Identify and enumerate preliminary : 1. NDI equipment procedures 2. Inspector requirements 3. Facility requirements
3. Final Design	• Experiment to assess factors affecting reliability • Demonstrate feasibility through "blind" procedures • Gather inspection time data • Update procedures and inspector requirements • Early field trials
4. Field Implementation	• Prepare validation assemblies • Finalize procedures and inspection requirements • Conduct controlled trials using independent inspectors • Conduct field trials with potential users • Assess training (& retraining) needs for inspectors • Industry Beta-site testing

The objective of any inspection validation exercise is to provide quantifiable evidence that a particular inspection methodology is capable of achieving a satisfactory inspection result. The validation process takes into account a number of specific issues ranging from human factors to the construction of suitable Validation Assemblies to the need for comprehensive and uniform validation exercises. It considers the numerous factors which affect the reliability of an

inspection methodology including the individual inspector, his equipment, his procedures and the environment in which he is working. The approach is based on the use of real-life Validation Assemblies which are full-scale structural assemblies containing known, realistic defects.

The process of validating inspection techniques involves the specification of structure and defect types, the production of full size sections of airframes which contain natural, fully characterized defects or realistic, engineered defects to represent these structures. Inspection of these Validation Assemblies must occur under conditions identical to those of the day-to-day inspection environment. The inspection validation process is a full-scale, realistic mock up of the daily activities of the inspector. The inspections performed are then independently assessed against industry standards in terms of inspector and instrumentation performance. In this regard, independence and objectivity are essential and the AANC, being removed from the aircraft industry, is set-up to assume this role. Some validation efforts may include the use of airline maintenance personnel who will perform inspections using normal working practices and under normal working conditions (lighting, heating, shifts, etc.).

3. Technology Development Process

Research and development (R&D) into new NDI technologies must keep pace with the expanding requirements for aircraft inspection if older aircraft are to remain economically viable. In order to benefit the air carriers, the promising R&D efforts must be converted into reliable and cost effective inspection instruments or procedures that can be incorporated as part of normal aircraft maintenance. For example, the results of the R&D efforts involving equipment development must be effectively transferred to instrument manufacturers so that efficient, cost-effective and user-friendly instruments can be made widely available in a timely manner. To enable efficient technology development, substantial work is also needed in the human factors field, including improved procedure development and more consideration of the skill levels and training needed by aircraft inspectors.

Technology development as defined here is the development and subsequent transfer of information, hardware, or both, to the aircraft manufacturers and/or airline operators. The term hardware is meant to include not only the development of new NDI instruments, but also any substantial improvement to existing instruments. For any hardware development, technology development will have occurred when a concept or prototype instrument or improvement is developed by an NDI instrument manufacturer into a viable inspection instrument available in the general marketplace. As a result of this development, a report on the capabilities and limitations of that new or improved inspection instrument, including its field derived validation data, will be prepared by the AANC and made available to the aircraft industry.

The AANC has two functions in the technology development process: first as evaluators of the technology and second as facilitators to assist in the timely conversion of that technology into useful inspections. The technology being considered may originate from within the FAA program, NDI equipment manufacturers, other government sources, an outside source, or the AANC itself.

A detailed Technology Development Process has been written by the AANC and is presented in Ref. [2]. In addition to presenting how the Technology Development Process is implemented, it also discusses issues such as patent rights, the approval process to proceed with AANC involvement in a project, and interactions between the project originator, equipment manufacturers, and the air transport industry. A copy of Ref. [2] is available upon request.

4. NDI VALIDATION CENTER

A. Description of Facility

The Validation Center is housed in a hangar at the Albuquerque International Airport. This site was chosen because of: 1) its close proximity to Sandia Labs, 2) ease of access for Validation Center users, and 3) access to repair depots and maintenance facilities located at the airport. Figure 1 is a photograph of the hangar building.

The Validation Center contains 16,875 square feet of aircraft storage space, 7,762 square feet of office and storage space, and 100,000 square feet of outdoor pad space within the airport security area. Within the Validation Center building, the main hangar - 135' wide by 125' deep - is large enough to hold a Douglas DC-9 or a Boeing 727 or 737 transport aircraft.

Currently, 2230 square feet of the Validation Center is devoted to offices, conference rooms, libraries, storage areas and light laboratories. This includes an office and multiple lab rooms dedicated to visiting experimenters. The high bay hangar features a decommissioned 737 aircraft which is a key element in the AANC Test Specimen Library. This particular aircraft was manufactured in 1968 and has experienced 46,400 pressurization cycles during 38,400 flight hours. The remainder of the Test Specimen Library is stored in adjacent rooms. It contains numerous full-scale specimens representing typical flaws found in airframe and engine structures (See Section 6: "AANC Test Specimen Library").

To address any specific concerns or needs you may have regarding hangar accommodations, equipment, test set-ups, etc., Appendix A contains a customer questionnaire which requests your feedback on these issues. Please complete the questionnaire and return it to your Experiment Coordinator.

In the hangar, there are 110v, 20 amp circuits and 220v, 50 amp circuits. The facility is equipped with seven step ladders ranging in working heights from 4 ft. to 12 ft. A B-1 Airstair (see Figure 2) work stand is also available; it is a set of wheel mounted stairs with a working upper platform of 4' 6" X 4' 4". Its height is adjustable from 3 ft. to 12 ft. and it has a maximum load rating of 750 lbs. The Center has scaffolding (4' X 6' working platforms) which includes a bridge arrangement to cross over the top of an airplane. Figure 2 shows photos of two of the most often used work stands: the B-1 Airstair and the aircraft scaffolding. Again, if you have special tool, power, or work stand requirements, including the need for a manlift truck, please notify your Experiment Coordinator and describe your particular needs in the Appendix A survey.

B. Large Aircraft Testbed Structures

One of the most important and widely used specimens in the Test Specimen Library is the "FAA/AANC Transport Aircraft Testbed." This specimen is a 25 year old Boeing 737 aircraft which possesses key aging aircraft features: subjected to numerous cycles (46,000 cycles; 38,000 flight hours), cold bond lap splice joint, no lap splice modifications (terminating actions), and extensive corrosion. It has a functioning Auxiliary Power Unit along with all of the cabin environmental controls and indicators located in the cockpit. In order to study inspection techniques in real-life field settings, we have retained one, non operational JT8D engine. Working control surfaces (hydraulic or electrical actuation) have also remained with the airplane as well as associated actuation controls and cockpit indicators. Figure 3 is a photo of the aircraft in the AANC hangar building.

Because of its versatility and ability to provide all of the 737 inspection requirements, the FAA/AANC Transport Aircraft Testbed is the key specimen in the AANC Test Specimen Library. In addition to permitting the assessment of the technical merits (reliability and sensitivity) of various NDI techniques, it also allows the AANC to evaluate human factors issues (e.g. environment, protocols), accessibility concerns (e.g. deployment, portability, need to remove peripheral items), and cost benefit data (e.g. inspection times, versatility). With a complete aircraft such as this, the AANC can study inspection techniques as they pertain to complete AD's. The 737 has been configured with different degrees of accessibility to simulate a variety of standard structural inspections. The forward section of the aircraft (including the first class section) has been left intact to provide conditions associated with light structural inspections ("A check"). Beyond the first class section, internal components have been removed (e.g. fiberglass lining, insulation blankets, floor boards) so that the aft portion of the aircraft is configured for complete internal structure accessibility. This degree of accessibility, shown in the Figure 4 photograph, simulates the maintenance environment during major structural inspections ("D Check").

Appendix B contains a series of 737 schematics which will be useful in designing your experiments. Fuselage stringer and frame locations are clearly labeled so that you can identify your desired inspection locations. During the course of your testing at the AANC hangar, you will be given varying degrees of guidance and immediate feedback regarding the structures you are inspecting. The degree of guidance and feedback will depend on the specific goals of your experiments (see Section 10: "Your Interaction With the AANC"). The schematics in Appendix B are also useful in linking inspections (requirements and procedures) to current practices (i.e. existing Air Worthiness Directives, Supplemental Structural Inspection Documents, Service Bulletins, etc.).

Two other large aircraft test structures housed in the hangar are fuselage sections from a DC-9 aircraft. This particular DC-9 is a former Eastern Airlines airplane which was based in Miami and flew in the Caribbean (Mfg. Date - 1973, Hours - 56520, Cycles - 64,360). The two fuselage sections which were cut for AANC use are: 1) forward fuselage section of the aircraft from the radar bulkhead back to station 280 (includes the forward passenger door, service door, cockpit, windshield, and four cabin windows), and 2) aft pressure bulkhead including several structural bays fore and aft of the bulkhead (fuselage station 924 to 1032). The forward section has documented corrosion problems around the windshield and the passenger door and air stair door frames while the aft bulkhead has experienced fatigue cracks. Figure 5 shows the DC-9 forward fuselage section.

C. Document Library

A document library is also available at the AANC facility. It contains appropriate literature relative to the FAA Aging Aircraft Program as well as aircraft structural repair manuals, corrosion prevention manuals, and maintenance manuals. Aside from the general aviation regulation documents, the aircraft specific documents cover Boeing 727 and 737 aircraft. A summary of the more important documents is provided below:

1. Maintenance Planning Data Documents (MPD)
2. Nondestructive Test Manual (NDT)
3. Corrosion Prevention Manual (CPM)
4. Structural Repair Manual (SRM)
5. Service Bulletins (SB)
6. Supplemental Structural Inspection Documents (SSID)
7. Aging Aircraft Corrosion Prevention and Control Program (CPCP) Task Cards
8. Air worthiness Directives (AD)
9. Federal Aviation Regulations (FAR)
10. Airline Maintenance Inspection Intervals
11. Documentation Which Accompanies the High Cycle Aircraft
    A. Maintenance Manual
    B. Illustrated Parts Manual
    C. Life Limited Parts List
    D. Aircraft Cycles and Engine Total Hours Log
    E. Record of Last Major Check
    F. Major Repair and Alterations Log

D. Environment, Safety, and Health (ES&H) Issues

Other important items associated with your activities in the Validation Center are the ES&H concerns. The AANC must be apprised of any hazards associated with your operations and any measures taken to mitigate them. **The survey in Appendix A asks a series of questions regarding safe operations. Your test plan should include a description of your equipment set up and test operations so that the AANC Facility Manager can assist you in your hazards assessment and can take the necessary actions prior to your arrival.** There should also be considerations given to environmental issues such as the use of chemicals at the Center. The Appendix A survey prompts you for this information as well.

5. NDI VALIDATION EXPERIMENT TEAM

A Validation Experiment Team has been assembled to aid your experiment planning process. The background and number of team members match the complexity of the experiment. Each team member has a specific role in planning and conducting the experiment; a brief definition including primary responsibilities follows.

1. *Experiment Coordinator* - determines viability of and plans experiment with the assistance of the NDI Technical Expert; coordinates efforts of all experiment participants listed below; assures sufficient documentation and reporting of experiment including proper data logging of inspection results; provides AANC briefing to user agency

2. *User Agency (Experimenter)* - conducts experiments in hangar; provides information to AANC regarding technique/equipment; provides all inspection results in acceptable format. **See Section 7 ("Inspection Data Archiving Requirements") and Section 8 ("Experiment Reporting Formats") for description of Experimenter's responsibilities.**

3. *NDI Technical Expert* - provides assessment of experiment through in-depth knowledge of NDI technique/equipment; primarily concerned with hardware and software aspects and comparisons of existing technique with previous versions, other similar equipment or competing technologies.

4. *Experiment Observer* - provides experiment coverage necessary to document deployment of equipment, inspection procedures, inspection limitations and problems encountered (e.g. inability to inspect certain geometries, computer shut-downs, time required to inspect areas); this person simply provides any pertinent observations to the Experiment Coordinator.

5. *Facility Manager* - furnishes suitable facility set-up and necessary support equipment; assures that all environment and safety concerns are addressed; provides safety, security, and hangar operations briefing to user agencies.

All of the people described above form the Validation Experiment Team. Using the experiment process described in this document and the definitions above, each participant can understand how they fit into the experiment planning and implementation. Proper documentation, reporting and archiving of all inspection results are three critical concerns. In general, all of the tests in the hangar will be considered Validation Experiments and will fit into one of the four phases defined in the NDI Validation Process document.

6. AANC Test Specimen Library and Database

A. AANC Test Specimen Library

The AANC Test Specimen Library (TSL) is a multi-faceted program which involves acquiring samples from numerous sources, characterizing the flaw profile in those samples, and incorporating the use of the specimens into the AANC NDI Validation Process.

The current, working definition of the Test Specimen Library is as follows:

The AANC Test Specimen Library is part of the FAA/AANC NDI Validation Center and consists of an array of full-scale, representative sections of airframe and engine structures which contain natural or realistic engineered defects in known locations. The specimens will be used to implement NDI validation efforts (equipment, procedures, etc.) and aid in the development of advanced NDI techniques. The library contains test items which range from small, "bench top inspectable" structures to a complete 737 aircraft. and large fuselage sections from a DC-9 aircraft. The library is a continuously expanding element of the Validation Center. The goal of the library is to present visiting experimenters with a full array of defect specimens which represent aircraft structures from the major U.S. and foreign airframe and engine manufacturers (both commuter and transport).

The TSL contains aircraft repair examples as well as pieces of panels, skins, frames, and other structural elements which exhibit one or more of the following defect attributes: corrosion, fatigue cracks, debonds, and fretting. These specimens are being used to assess NDI equipment and procedures and are available for use by all AANC customers. Two of the library's specimens are shown in Figures 6 and 7. Prior to beginning any experiments at the Validation Center you will meet with your Validation Experiment Team to select the set of TSL specimens which will provide the maximum benefit to your test series.

In addition to the 737 and DC-9 test beds described in Section 4, other TSL specimens include: adhesive bond calibration standards, riveted joints with EDM notches, lap joint sections cut from a 707 aircraft, fabricated lap splice panels which have been fatigued, and a circumferential butt joint cut from a 707. An important set of specimens is the AANC Probability of Detection (POD) Experiment Test Specimens. These well-characterized specimens are specially fabricated panels (20" W X 20" H) which model the skin portion of a lap joint. They consist of two plates fastened together, using three rows of rivets, with a 3" overlap. Specific rivet hole crack distributions were generated in these panels through carefully controlled loading schemes. A complete description of these panels is provided in Reference [3].

B. AANC Test Specimen Library Database

A key element in the successful operation of the Validation Center is a means to completely support both the "Validation Process" and the "Test Specimen Library." The TSL Database supports these activities - storage of inspection data and specimen drawings and comprehensive NDI assessments - in an automated, time efficient manner. Currently, the TSL Database is being enhanced to accommodate items such as: 1) remote access to the database through phone modems, 2) the ability to operate on both Macintosh and PC platforms, and 3) automated correlation between library specimens and associated inspection requirements. The database is designed to support the management, experiment planning and NDI assessment portions of the AANC program.

The Test Specimen Library Database is used to store and access all information created and gathered by the AANC program. It assists "front end" experiment planning by storing and retrieving basic information about samples in the database such as description, history, and notes on characterization tests. It also provides the means to archive the detailed images (NDI data) acquired during inspections. Users are able to query the database and locate specimens based on numerous description and history categories (e.g. flaw type, specimen size, aircraft type, location on aircraft). Users can also issue reports from these searches and can view photograph images of the specimens. The database menus shown in Figures 8 and 9 highlight these data storage and specimen selection/sorting capabilities.

The database also aids AANC NDI validation activities through automated data retrieval. It allows the AANC to accurately and efficiently make NDI technique comparisons and to correlate results from different inspections. In the next section you will be given information regarding the transfer of your inspection data into this database.

7. INSPECTION DATA ARCHIVING REQUIREMENTS

A substantial portion of the Center's NDI activities involve archiving, retrieving and comparing specimen inspection data. The Test Specimen Library Database described above is able to archive, retrieve, and compare the specimen inspection results, as well as specimen test reports, aviation industry citations, structural repair manual schematics and other engineering drawings. AANC validation activities are substantially aided by the automated comparisons of inspection results afforded by the database. Further, the database provides a tool for AANC customers to: 1) assess their technique at different points in time (i.e. improvements from one visit to another), and 2) compare their techniques with other NDI methods which may perform the same inspections.

In order to maintain a database which is valuable to the NDI community, the AANC inspection data logging process must be comprehensive and accurate. Towards that end, your contribution to the database is important. At the end of your test series at the AANC, you will be expected to provide a set of your data for inclusion in the database. Your inspection results can be stored directly from data acquisition system disks. This eliminates the time consuming, costly, and mass storage intensive scanning of inspection hard copies. The database can accept image files stored in numerous formats and Table II summarizes these formats. If you cannot supply your data in an appropriate format, indicate this in the Appendix A survey. In all probability, conversion software can be acquired to accommodate your specific data file format.

The electronic storage media used to transfer information can be floppy disks (5 1/4" or 3 1/2"), Bernoulli disks, portable hard disks, or optical disks. Customers should make provisions with their Experiment Coordinator to assure that the proper hardware is available at the Center.

TABLE II : Technical Specifications for Acceptable SDL Database File Formats

File Type	Format Description
BIT/RLE	Lotus BIT image files
OS2/BMP	1-, 4-, 8-, and 24-bit OS/2 bitmap files
Windows BMP	1-, 4-, 8-, and 24-bit Windows bitmap uncompressed files
CGM	Integer, floating point, & fixed binary encoded Computer Graphic Metafiles
CUT	Dr. Halo's CUT files
Mac EPS	Extracts the preview bitmap file
PC EPS	Extracts the preview TIFF file
GIF	Compuserve's GIF 87a & 89a specifications
GPR	Apollo's GPR files (chunky 7 planar)
IFF/ILBM	Amiga's IFF/ILBM format (including HAM)
GEM IMG	Digital Research's image file
IMG	Visilog's gray-scale IMG files
MacPaint	Supports Macpaint files
PCX	ZSoft's PCX format (including 24-bit image)
Photoshop	Adobe black & white, gray-scale, index color, & direct color images
Lotus PIC	PIC files from Lotus 1-2-3
PCPaint PIC	VGA PIC files
PixelPaint	SuperMac's PixelPaint version 1.0 files
RGB	24-bit Silicon Graphics' RGB files
RIFF	Letraset's black & white, gray scale, and RGB images
RIX	Uncompressed RIX files
Sun Raster	SunRaster format (including 1-, 8-, & 24-bit files)
Targa	8-, 16-, 24-, & 32-bit Targa files
TIFF	Version 5.0 TIFF files
X11 Bitmap	X Window standard bitmap raster files
X11 XWD	X Window Dump chunky & planar files (1-, 4-, 8-, & 24-bit images)

A. Data File Naming Convention

Associated with the entry of your data into the AANC database, there is a file naming convention which we request that you follow. The file naming convention described below will allow: 1) the database to function to its fullest capabilities, 2) a database user to immediately determine the location being imaged and 3) the database to implement searches on specimen inspection histories. Following are the two file naming conventions for:

1. Logging inspection data from small specimens -

   filename = "TSL β . ϕ" (e.g. "TSL165.Rt")

   where:

   β = AANC Test Specimen Library Specimen Number

   ϕ = Descriptor for reference location on specimen; allows user to determine exact location which produced image found in file

2. Logging inspection data from 737, DC-9 or other large aircraft sections -

   filename = "S ω _ ψ. β" (e.g. "S20L_780.100")

   where:

   ω = Stringer number and side of aircraft (left or right)

   ψ = Fuselage body station number

   β = AANC Test Specimen Library Specimen Number

The database will be able to conduct the necessary searches even if you stray slightly from this format. As long as the basic kernel of information is in the title, it is acceptable to place additional information in the file names. A similar convention can be used when inspecting wing structures where stringers and spars provide the "grid" for locating inspection areas. **Please discuss all data transfer issues with your Experiment Coordinator before traveling to the AANC.**

8. EXPERIMENT REPORTING FORMATS - CUSTOMER INPUT TO CENTER ACTIVITY REPORTS

An important aspect of data archiving is the reporting process which provides comprehensive documentation for each test series. The final AANC report is actually a compilation of three separate write-ups from the following contributors: the Experiment Coordinator, the Experimenter, and the NDI Technical Expert. You, as the Experimenter, will be asked to provide your portion of this AANC activity report. The write-ups are unaltered and are assembled into one report along with the standardized cover sheet shown in Figure 10. In experiments where there are external observers from industry, any reports that they write will be incorporated into the single AANC document.

The AANC activity report will be scanned into the AANC Test Specimen Library Database for future reference. It will also be distributed to our sponsors at the FAA Technical Center. Discuss this documentation process with your Experiment Coordinator. Let him know if your report contains proprietary information and requires a limited distribution and/or controlled database access.

Following is a summary of expected contributions from the experiment participants.

1. *Experiment Coordinator* - consolidates their observations and those of others into the summary section; also incorporates information obtained during pre-experiment and post-experiment meetings with specific emphasis on issues highlighted by AANC experiments (e.g. problems, modifications required, assistance provided by AANC tests).

2. *NDI Technical Expert* - input should be very hardware oriented along with procedural comments (what was system like 1 year ago?, 6 months ago?, etc.); discuss recent experiences in light of the new features or modifications being tested and evaluated at the AANC; present end results of the test series: necessary changes, technical problems observed, suggested enhancements based on the AANC's knowledge of the aviation industry's needs.

3. *Experimenters* - discuss their test plan including objectives and approach; provide technical information: technique background and instrumentation including mechanical details such as deployment; mention improvements over previous versions of system if applicable; describe tests and corresponding results; provide an overall assessment of capabilities/limitations/changes which will be implemented as a result of AANC evaluations (include changes already implemented to show immediate benefits of visit to the Center); discuss potential future plans: changes, new prototypes, future experiments at the Center.

If the inspection results are in the form of digitized images, then it is not necessary for all of the images to be included in the experimenter's report. [Three, four, and five day experiments can result in the acquisition of hundreds of image files]. **However, a select number of examples should be included in the experimenter's report. They should be sufficient to represent the different findings from the tests (e.g. flaw types, flaw sizes, flaw location, structural configurations tested). Also, the report figures should be annotated with appropriate comments so that the report adequately documents the inspection findings. Extensive flaw findings beyond the chosen pictorial examples should be documented in tabular form.** All of the raw data, although not included in the report, will be entered into the Test Specimen Library Database (see Section 7: "Inspection Data Archiving Requirements").

9. FAA AGING AIRCRAFT PROGRAM AND ROLE OF AANC

A. The National Aging Aircraft Research Program

The Aviation Research Act of 1988 directs the FAA to develop technologies and conduct data analysis for predicting the effects of aircraft design, maintenance, testing, and fatigue on the life of aircraft and to develop methods of improving aircraft maintenance technology and practices, including NDI of aircraft structures. As a result of the Aviation Research Act and concerns related to the increasing age of the air carrier fleet, the FAA developed the National Aging Aircraft Research Program (NAARP) in 1989. Its intent is to ensure the structural integrity of high-time, high cycle aircraft. The NAARP meets the requirements of the Aviation Safety Research Act by expanding the FAA's role to include research for improving aviation safety.

The objective of the FAA is to supplement industry's technology development work through coordination with industry and the facilitation of promising research. With industry participation in virtually every aspect of the NAARP, research activities are focused on structural integrity, loads analysis, maintenance and inspection technology, information management, and improvements to training and human performance. To facilitate this work, the FAA Technical Center directs research undertaken by industry, academia, and other government agencies. The Figure 11 chart summarizes the NAARP participants including the industrial advisory organizations and the FAA sponsoring agencies.

B. Inspection Reliability Assessment, Technology Development and the AANC

The purpose of inspection technology development is to deploy improved tools and procedures for inspecting transport and commuter aircraft and engines. This implies that new inspection techniques are available to trained personnel who can use them and that they are confident that the new techniques represent substantial improvements over existing methods. These techniques must be improved to cope with the more rigorous inspection demands of modern aircraft.

The NAARP is using several resources to achieve its objectives. These resources have been integrated into a single management structure, as depicted in Figure 12, to ensure: 1) an appropriate mix of near, mid, and long-term research, 2) integration of knowledge from organizations outside the FAA's purview, 3) allocation of funds to most efficiently reach program goals and, 4) mechanisms for encouraging and integrating innovative technologies. The AANC is shown as a processor of NDI research in Figure 12 and provides the link between NDI development and achieving new means for compliance with mandated inspections.

To ensure that the NDI techniques are superior to existing practice, they must be assessed and validated (i.e. the reliability of the procedure should be determined and compared with existing practice). The effectiveness of the NDI procedure should be determined from both a cost and time standpoint. Accordingly, the FAA has established the Aging Aircraft NDI Validation Center (AANC) to qualify candidate inspection techniques, evaluate their effectiveness in meeting specific inspection requirements, and determine their probable value in appropriate inspection applications. Figure 13 shows how the AANC conducts activities to validate advanced NDI techniques and move new technology to the aircraft maintenance hangar. AANC interactions with NDI technique developers is also clearly shown.

10. YOUR INTERACTION WITH THE AANC - PLANNING *YOUR* EXPERIMENTS

Now that you have familiarized yourself with the AANC and the FAA's Aging Aircraft Program, you are prepared to plan productive experiments with your AANC team. In order to optimize your time at the Center, you should first fill out the survey in Appendix A and draft a brief test plan - including NDI technique description, equipment set-up, test objectives and structural inspection plans - for AANC review. Your Experiment Coordinator will then contact you to begin discussing details such as: 1) type and range of applications of your NDI technique, 2) specimen selection (blind tests vs. calibration tests), 3) type of feedback desired, 4) maturity of your technique vs. type of assessments to be made and data to be acquired and even, 5) an overall validation program which includes a series of visits to the Center. This total plan should detail specific goals for each visit with provisions for moving toward formal, quantitative NDI validation. The appropriate NDI Technical expert will also participate in these discussions.

As a developer of aircraft inspection techniques, you are an AANC customer and the goal of the Center is to aid your development process through in-house experiments and constructive feedback. The status of your NDI process may currently be anywhere from initial conceptual ideas to a turnkey device which is field implementable and ready to market. The AANC actively works with researchers or companies at either end of the development spectrum. We utilize discussions with the FAA, the manufacturers, and the airlines to allow us to optimally utilize our center and to better serve your individual needs.

Many of our visitors are quite familiar with aircraft structures and inspection requirements and therefore, need very little guidance in designing experiments. The AANC Validation Experiment Team will provide assistance as necessary and will only redirect your efforts when they begin to stray from aviation industry needs. The nature of your experiments will be established by the state of maturity of your technique. As mentioned earlier, the Validation Process described in Section 2 details the number and type of AANC activities associated with the various stages of NDI development (see especially Table I).

The AANC will not impose restrictions on your activities unless you are participating in a formal validation process which involves issues such as blind samples, specific and controlled applications and experiment protocols. These formal validation processes are carried out on late Phase 3 and Phase 4 NDI techniques where the level of maturity warrants greater AANC involvement. These experiments must be carefully designed in order to properly and thoroughly evaluate the NDI technique (including quantitative assessments). NDI methods at Phase 1 and 2 development levels, on the other hand, may just need experience inspecting aircraft and access to specimens with known flaws so that continued improvements can be made.

Whenever possible, inspections should be carried out in accordance with existing aircraft inspection requirements (AD's, SSID, SB's, etc.). This is especially important for the more mature NDI methods (Phase 3 or 4) since potential uses of any techniques and hardware must be tied into current maintenance practices. Also, economic considerations should be used to focus some experiments where, for example, it is desirable to demonstrate/measure inspection time and ease of use.

Aside from experiments on mature technology which attempt to quantify the reliability of NDI techniques through the use of "blind" defect specimens and beta site testing, most of the Center validation activities are not intended to "grade" a customer's equipment or technique. It is hoped that your use of the Center will be viewed as an opportunity to improve your system through a better understanding of aviation industry needs in general and specific inspection requirements in particular.

Before coming to the Center to conduct any experiments, please be certain that all of your questions have been answered . You are welcome to make a preview visit to the AANC if you feel that it would help you plan more productive experiments.

A. Outline of Experiment Procedures - What to Expect at the AANC Hangar

Once you arrive at the AANC hangar, the standard procedure for conducting experiments is as follows:

1. Customer receives AANC program briefing.
2. Facility manager reviews environment, safety and health issues and facility security
3. Pre-Test Meeting with Validation Experiment Team -
    - A. Customer provides briefing on NDI technique and equipment
    - B. Review test plan and select appropriate specimens
    - C. Experiment Coordinator reviews role of AANC in experiments
    - D. Discuss what and how assessments will be made
    - E. Determine method for archiving inspection results
    - F. Develop final test plan based on above discussions
4. Experiment Coordinator sets up schedule for facility support during planned testing
5. Customer conducts experiments with appropriate real-time documentation by Validation Experiment Team
6. Post-Test Meeting with Validation Experiment Team -
    - A. Customer provides briefing on inspection results, lessons learned, changes anticipated, plans with regards to future AANC visits
    - B. Open discussion of observations
    - C. Review of inspection results
7. *Establish schedule for completing Activity Report on experiments*
8. Establish a schedule for archiving data into the TSL Database.

B. Important Phone Numbers

All numbers are area code (505).

AANC Program -

Pat Walter (AANC Program Manager) : 844-5226
Jo Ann Keicher (AANC Program Administrative Assistant) : 845-8859

Ken Harmon (Hangar Facility Manager) : 845-8686, 843-8722 (hangar)
Craig Jones (Experiment Coordinator) : 845-9063
Dennis Roach (Project Engineer, Experiment Coordinator) : 844-6078
Floyd Spencer (Experiment Designer, Experiment Coordinator) : 844-5647
Phil Walkington (Experiment Support) : 844-1501

NDI Technical Experts -

Al Beattie (Acoustic Emissions) : 844-8937
John Gieske (Ultrasonics, Eddy Current) : 844-6346
Bruce Hansche (Coherent Optics) : 844-3469
David Moore (Eddy Current, Experiment Coordinator) : 844-7095
Rich Shagam (Visual, Thermography) : 845-9079
Kyle Thompson (Radiography) : 844-0347

Sandia Labs Fax Number : 844-8711

NDI Validation Center Hangar : 843-8722
843-8706 (FAX)

C. Places to Stay

Figure 14 is a map showing how to get to the AANC hangar facility from the airport and Sandia Labs area. Hotels located within the coverage of this map and less than a five minute drive from the hangar are:

1. Fred Harvey Best Western : 843-7000
2. Best Western Airport Inn : 242-7022
3. Marriott Courtyard : 881-9464
4. Radisson Inn : 247-0512

It is hoped that this information packet has given you an understanding of how the AANC fits into the FAA's Aging Aircraft Program and how it can serve your needs. Our role in helping you move your NDI technique to the hangar floor and your responsibilities in conducting experiments at the Center should also be clear. Thank you for taking the time to learn about our activities at the AANC. We look forward to working with you to develop and validate reliable aircraft inspection techniques.

REFERENCES

1. Spencer, F., "The Role of the Aging Aircraft NDI Validation Center in the FAA Validation Process", AANC Document Submitted to the FAA, dated 7/14/92

2. Phipps, G., "The NDI Technology Development Process as Implemented by the Aging Aircraft NDI Validation Center", AANC Document Submitted to the FAA, dated 7/14/92

3. Spencer, F., Borgonovi, G., Roach, D., Schurman, D., and Smith, R., "Reliability Assessment at Airline Inspection Facilities Vol. II: Protocol for an Eddy Current Inspection Reliability Experiment", DOT/FAA/CT-92/12, II, May 1993

TABLE I : Technical Specifications for Acceptable SDL Database File Formats	
File Type	**Format Description**
BIT/RLE	Lotus BIT image files
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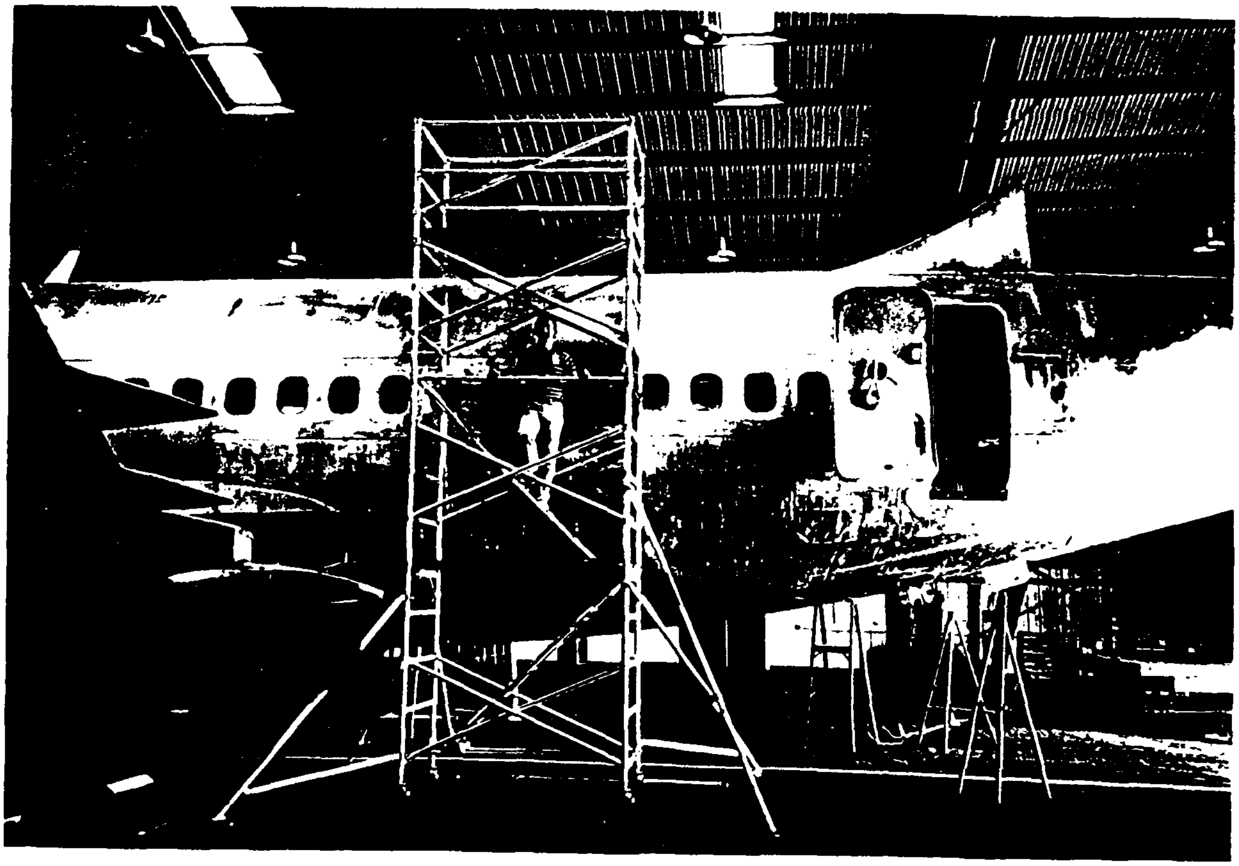
Windows BMP	1-, 4-, 8-, and 24-bit Windows bitmap uncompressed files
CGM	Integer, floating point, & fixed binary encoded Computer Graphic Metafiles
CUT	Dr. Halo's CUT files
Mac EPS	Extracts the preview bitmap file
PC EPS	Extracts the preview TIFF file
GIF	Compuserve's GIF 87a & 89a specifications
GPR	Apollo's GPR files (chunky 7 planar)
IFF/ILBM	Amiga's IFF/ILBM format (including HAM)
GEM IMG	Digital Research's image file
IMG	Visilog's gray-scale IMG files
MacPaint	Supports Macpaint files
PCX	ZSoft's PCX format (including 24-bit image)
Photoshop	Adobe black & white, gray-scale, index color, & direct color images
Lotus PIC	PIC files from Lotus 1-2-3
PCPaint PIC	VGA PIC files
PixelPaint	SuperMac's PixelPaint version 1.0 files
RGB	24-bit Silicon Graphics' RGB files
RIFF	Letraset's black & white, gray scale, and RGB images
RIX	Uncompressed RIX files
Sun Raster	SunRaster format (including 1-, 8-, & 24-bit files)
Targa	8-, 16-, 24-, & 32-bit Targa files
TIFF	Version 5.0 TIFF files
X11 Bitmap	X Window standard bitmap raster files
X11 XWD	X Window Dump chunky & planar files (1-, 4-, 8-, & 24-bit images)

FIGURE 1 : FAA/AANC NDI Validation Center

A. B-1 Airstair



B. Scaffolding

FIGURE 2 : Work Platforms Available for Access to Inspection Areas

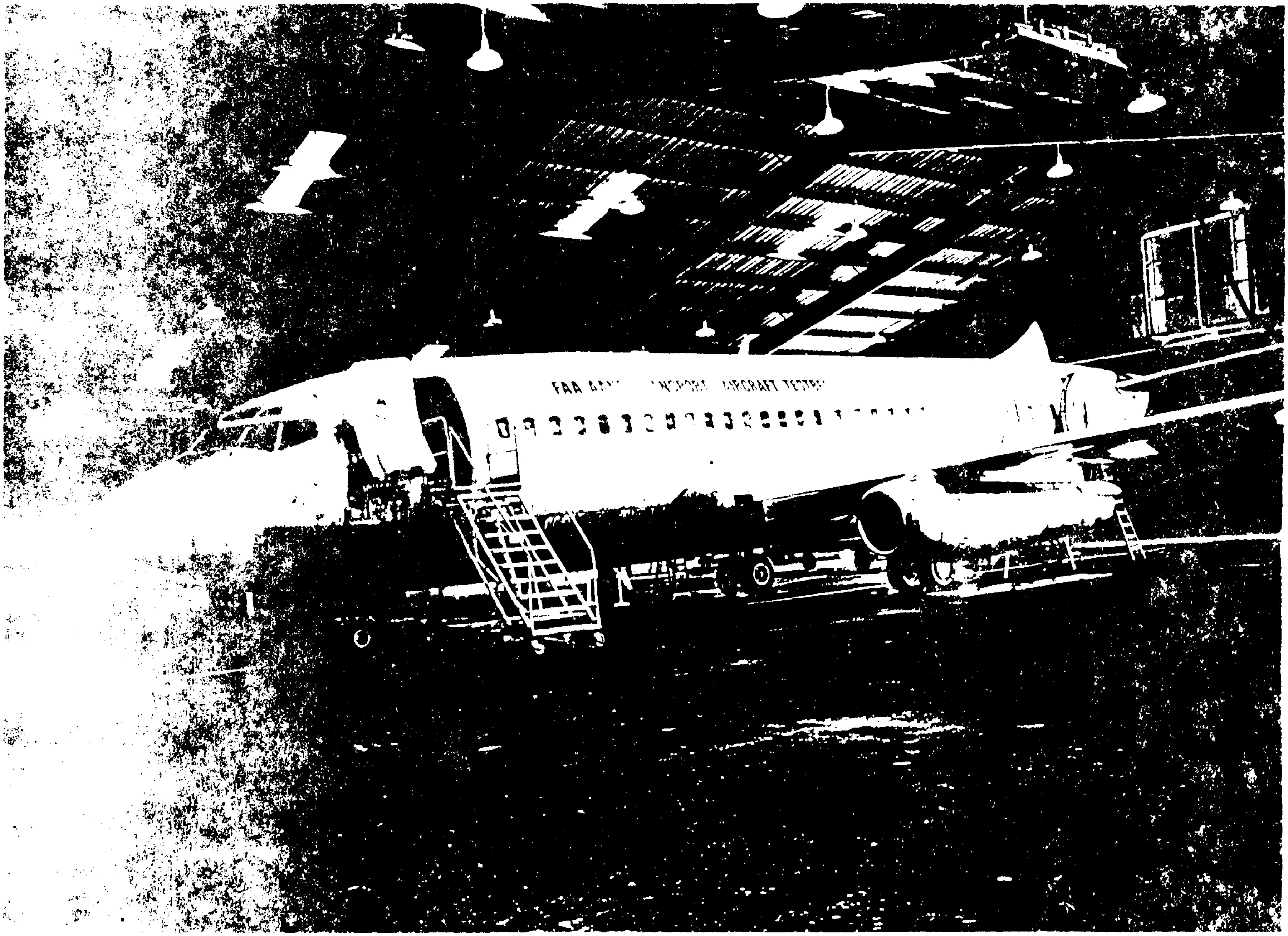
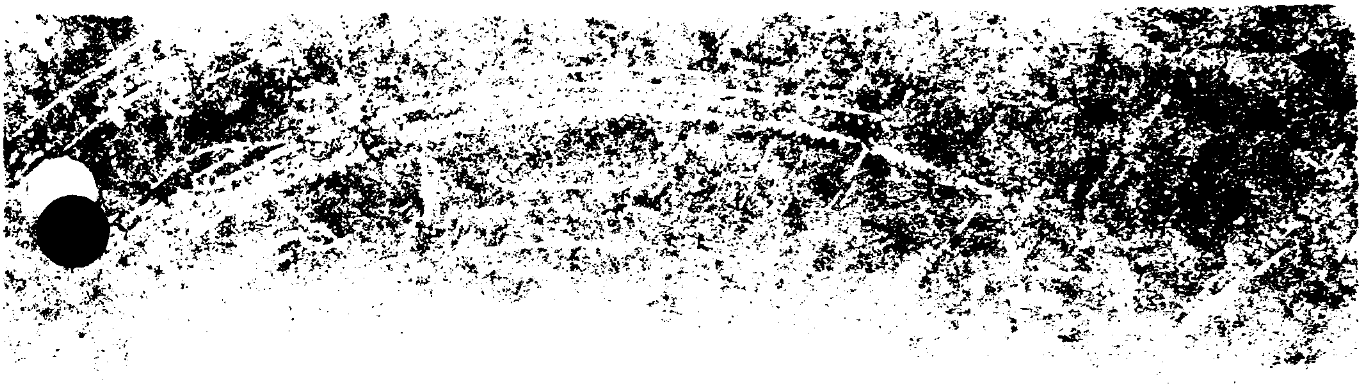


FIGURE 3 : FAA/AANC Transport Aircraft Testbed



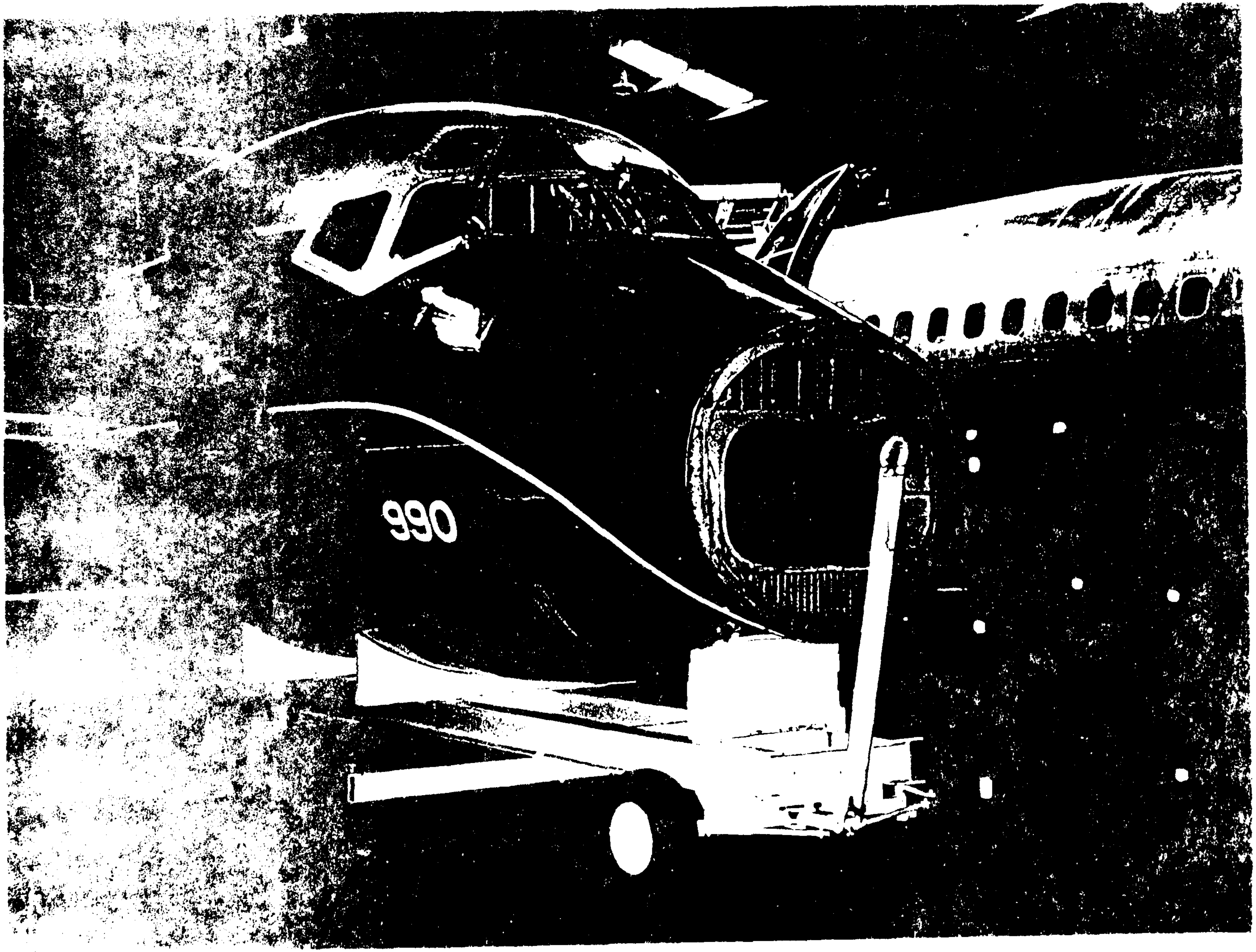
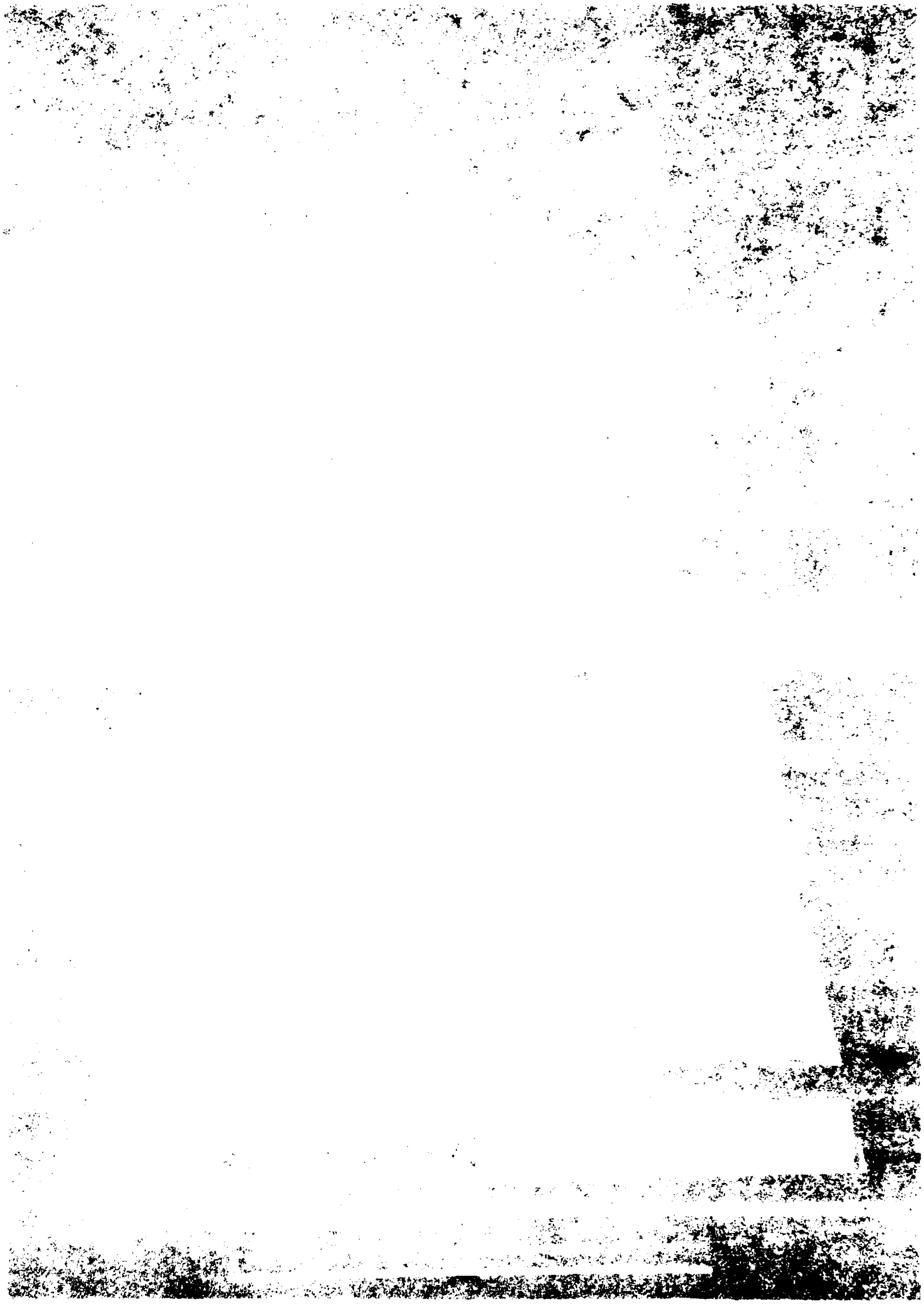


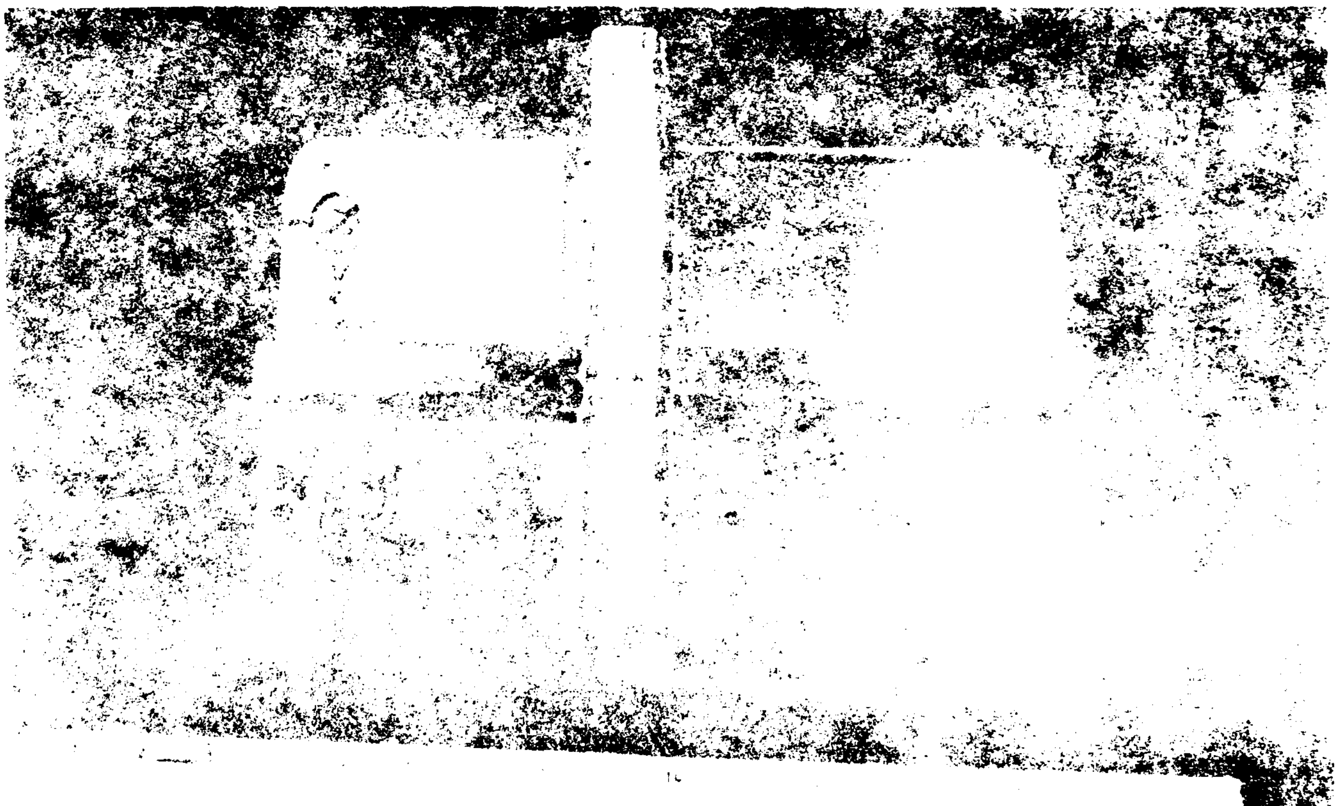
FIGURE 5 - DC-9 Forward Fuselage Section



b. Back/External View

FIGURE 6 - 747 Belly Skin With Repair Doubler

A. Front External View



B. Back/External View

FIGURE 7 : Complete Structural Section From a 737 Aircraft Which
Includes a Longintudinal Lap Splice Joint
and a Circumferential Butt Joint

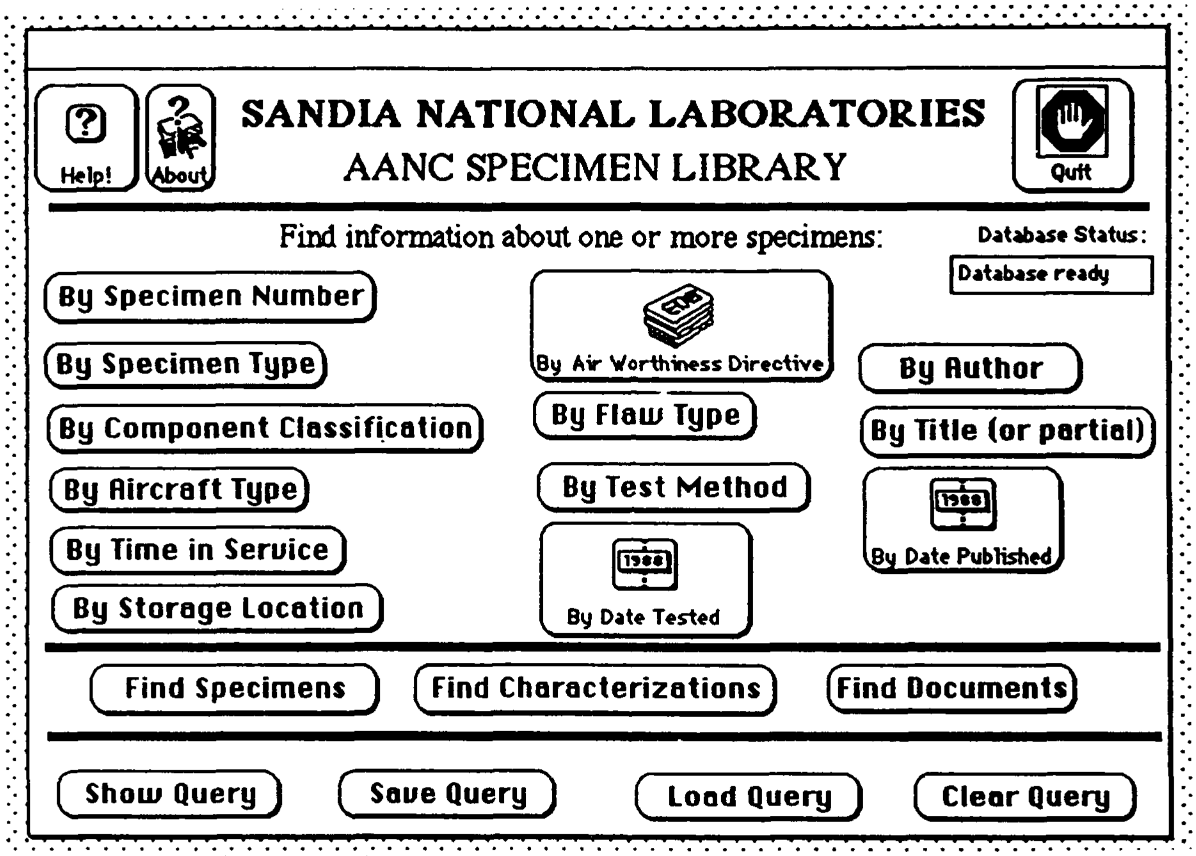


FIGURE 8 : Entry Level Menu for Sample Defect Library Database Showing Ability to Support Specimens by Predetermined Categories

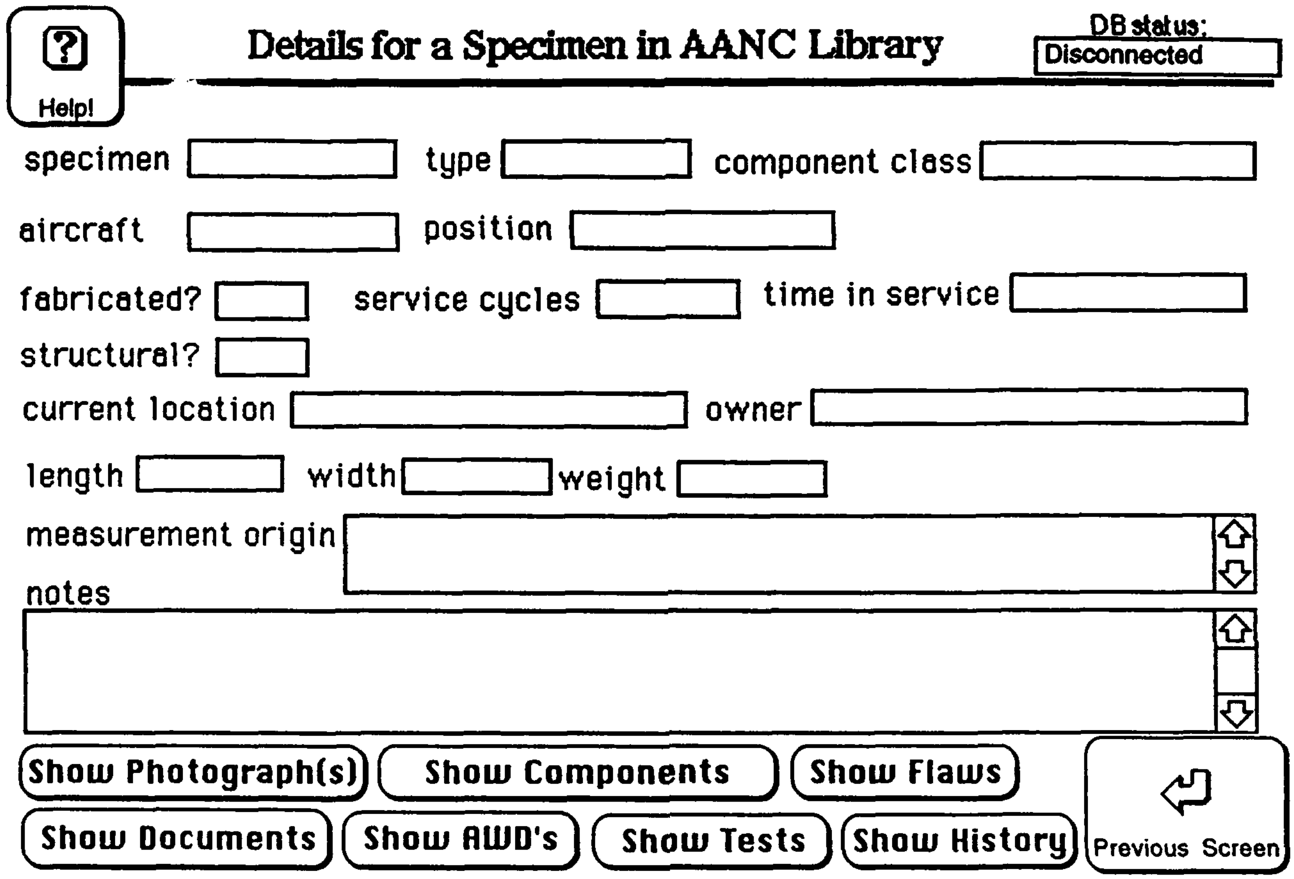


FIGURE 9 : Individual Specimen Data Sheet With Bottom Menu Used to Correlate Specimen With Critical Information

AGING AIRCRAFT NDI VALIDATION CENTER

ACTIVITY REPORT

Activity : Application of thermography system to AANC 737 aircraft and select Sample Defect Library Specimens

Experimenter : Wayne State University, Bob Thomas
Center for Aviation Systems Reliability (CASR)

Test Dates : March 14 - 18, 1993

Purpose : Assess performance of Wayne State/Thermal Wave Imaging, Inc. new prototype thermography system : 1) address deployment issues and, 2) investigate capability to detect debonds and corrosion.

Experiment Coordinator : Dennis Roach, AANC

NDI Technical Expert : Gary Phipps, AANC

Specimens Inspected :

737 Transport Aircraft Testbed - various lengths of fuselage lap splice joints including belly, crown, section aft of right wing, and sections around aft lavatory and luggage compartment.

Stringer 10L from Fuselage Station 350 to 500 and 747 to 947
Stringer 14L from Fuselage Station 360 to 500 and 747 to 937
Stringer 17L from Fuselage Station 957 to 986
Stringer 19L from Fuselage Station 390 to 490
Stringer 20R from Fuselage Station 847 to 947
Stringer 20L from Fuselage Station 787 to 937
Stringer 25R from Fuselage Station 747 to 947
Stringer 26R from Fuselage Station 328 to 510
Stringer 27R,L from Fuselage Station 817 to 907
Stringer 28R from Fuselage Station 380 to 510

Small Sample Defect Library Specimens -

747 belly skin with repair/corrosion : AANC # 113
Fabricated lap splice with corrosion: AANC #'s 115-122

Results : The performance of the Wayne State thermography system was evaluated in a realistic hangar environment. The AANC tests demonstrated the need for quantitative skin thickness measurements and use of standardized color palettes to aid image interpretation and allow for repeatable results. The importance of wide area coverage and flexibility in equipment deployment was also emphasized. Finally, the need to inspect the inner skin surface was identified. Wayne State is working on these modifications and plans to apply an improved thermography system at an upcoming Tinker Air Force Base test.

FIGURE 10 : Standardized Cover Sheet for AANC Activity Reports

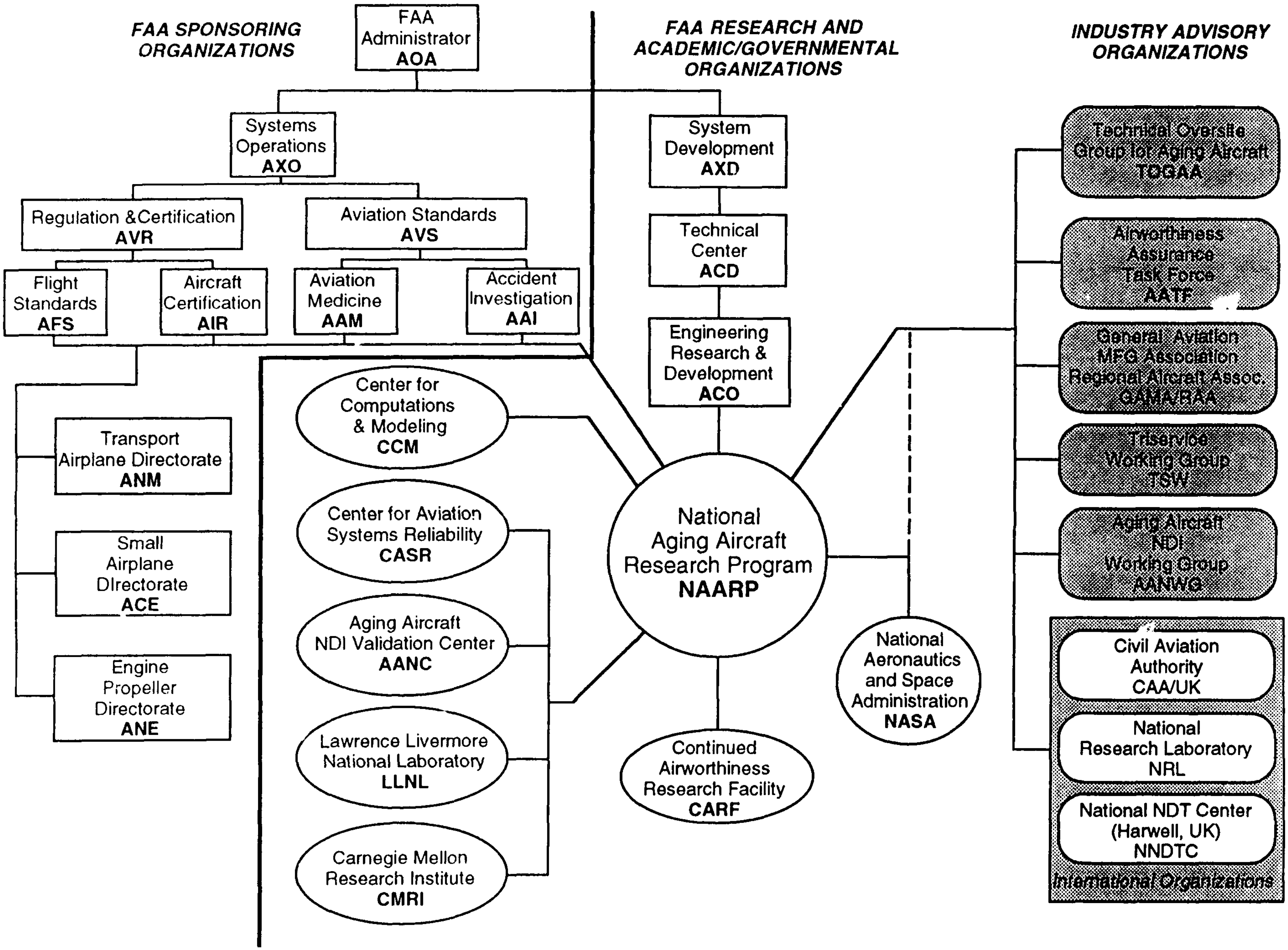


FIGURE 11 : FAA R & D Program Organization

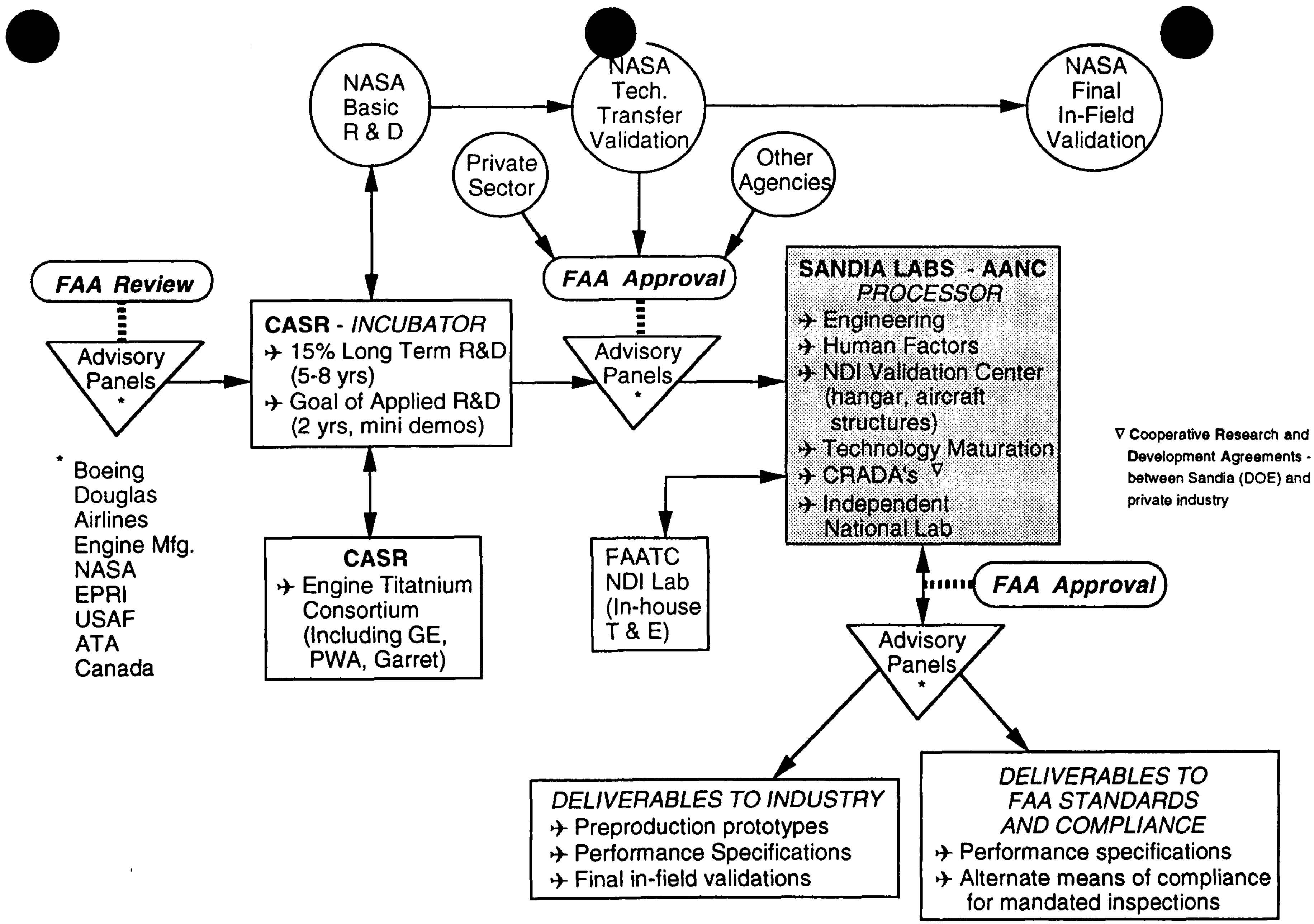


FIGURE 12: Integration of NAARP NDI Research Efforts

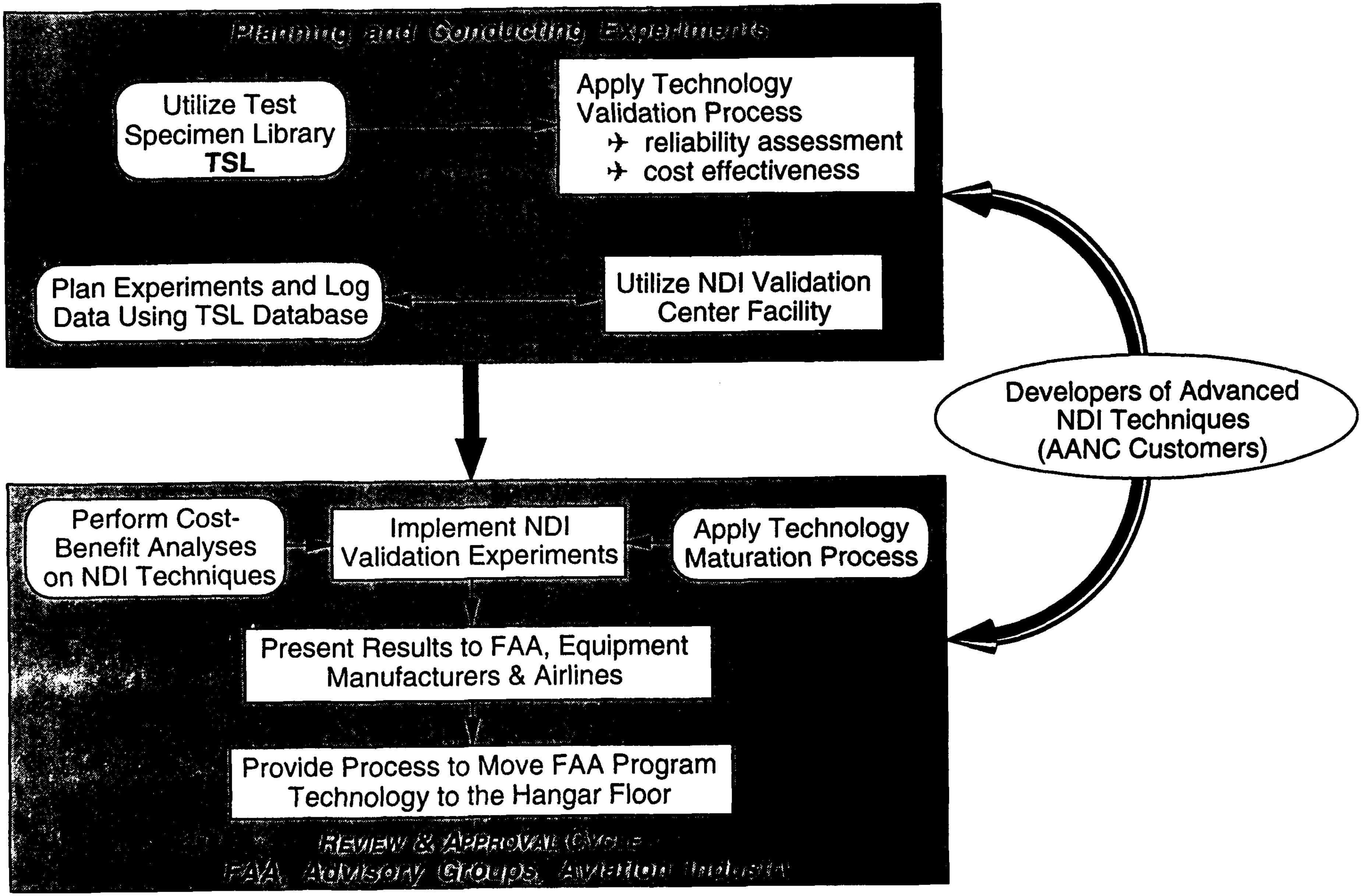


FIGURE 13 : Implementation Plan For AANC Activities

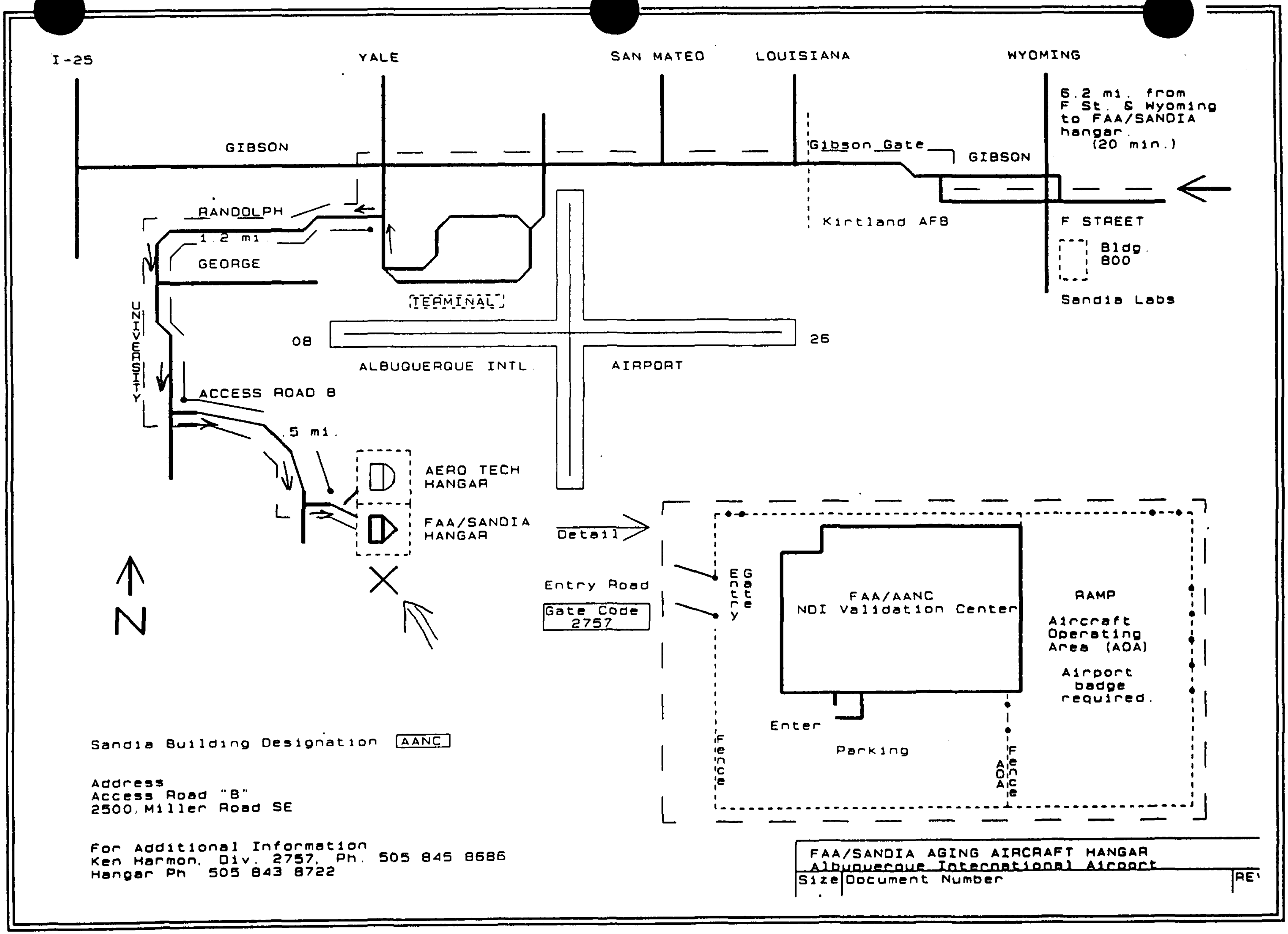


FIGURE 14 : Map to NDI Validation Center

APPENDIX A

CUSTOMER SURVEY

FOR

EQUIPMENT, SAFETY,

AND HEALTH CONSIDERATIONS

NDI VALIDATION CENTER CUSTOMER SURVEY: Test Equipment, Safety and Health (ES&H) Considerations

Please answer all questions as thoroughly as possible and continue answers on separate sheets if necessary. The following questions will be used to assess your needs and to allow the AANC to provide all of the necessary facility support.

1. List your name, affiliation (with phone number), NDI technique, and anticipated test dates at the AANC (if known).

2. Will you bring chemicals to the facility for your test program? Provide an inventory of the chemicals you plan to bring on site including the quantities you expect to use. Material Safety Data Sheets (MSDS) are required for all chemicals. Mixtures of your own design can be addressed by a list of the ingredients and the MSDS's for each ingredient. If you cannot supply MSDS's for your chemicals, please advise us thirty days in advance so that we may acquire them.

Chemical	Quantity	MSDS (Yes/No)

3. Will your test program require the use of electric, pneumatic or other special tools? If so, specify.

4. Do you need access to specific areas on the 737 testbed aircraft (e.g. normally inaccessible internal structure, areas under shrouds, engine components)? If so, specify.

5. The facility has 110v, 20 amp circuits and 220v, 50 amp circuits. There are also four 110v, 3 outlet extension cords available. If you have additional power requirements, specify below.

6. The facility is equipped with the various step ladders, work stands, and scaffolding described in Section 5: "NDI Validation Center". Discuss your requirements for access to external portions of the aircraft so that we may have the appropriate work stations in place for your experiments.

7. Discuss any hazardous operations associated with your experiments (e.g. laser light source requires restricted access to observers, high power equipment requires special precautions).

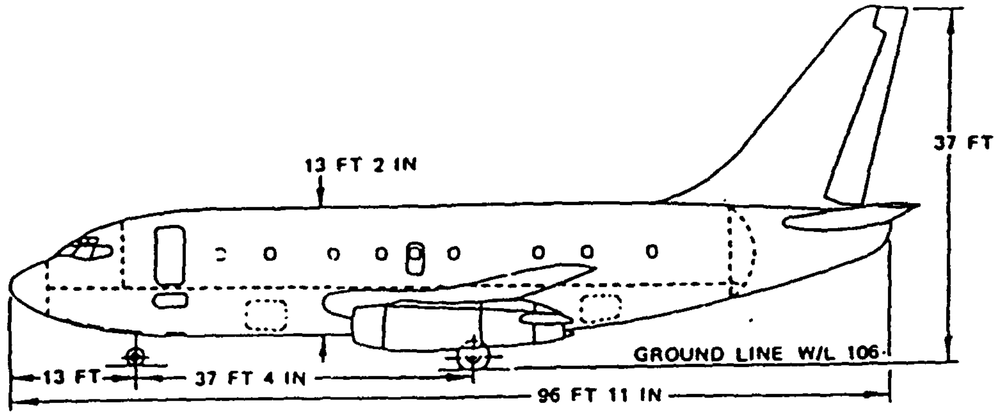
8. With your knowledge of the AANC hangar facility and your expected test set up, discuss your facility needs in general. This includes items such as use of a separate "light lab" or office, work benches, equipment carts, phone line for computer modem hook-up, special lighting, manpower support or any other special needs not addressed above.

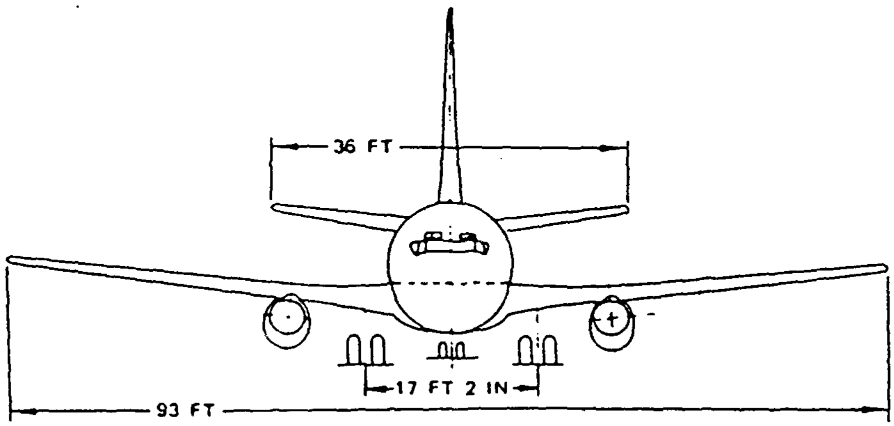
Please return the survey to your Experiment Coordinator at the following address:

Sandia National Labs
Aging Aircraft NDI Validation Center
Box 5800
Dept. 2757 MS-0616
Albuquerque, NM 87185-0616

APPENDIX B

737 AIRPLANE SCHEMATICS





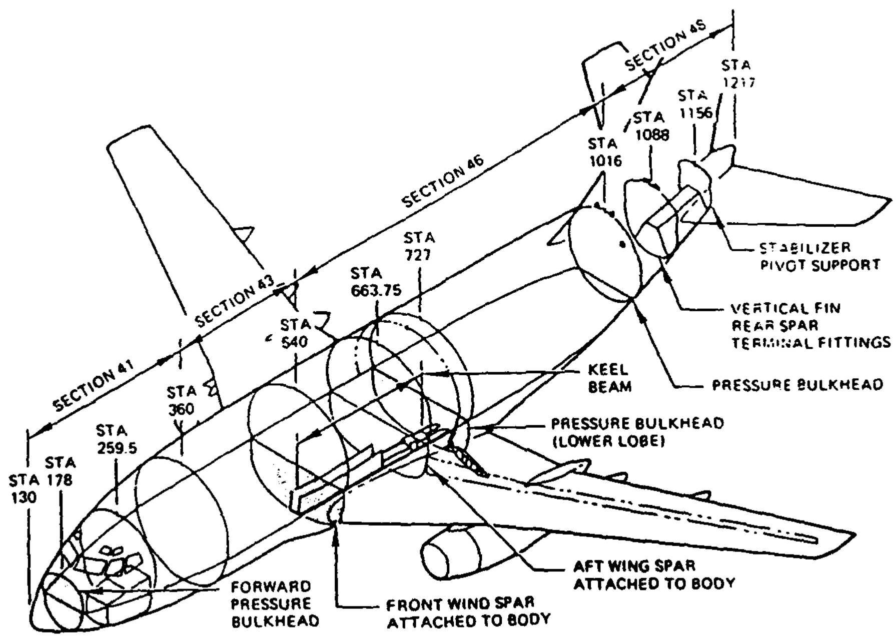


FIGURE B-1 : Principal Dimensions and Major Fuselage Components of 737 Airplane

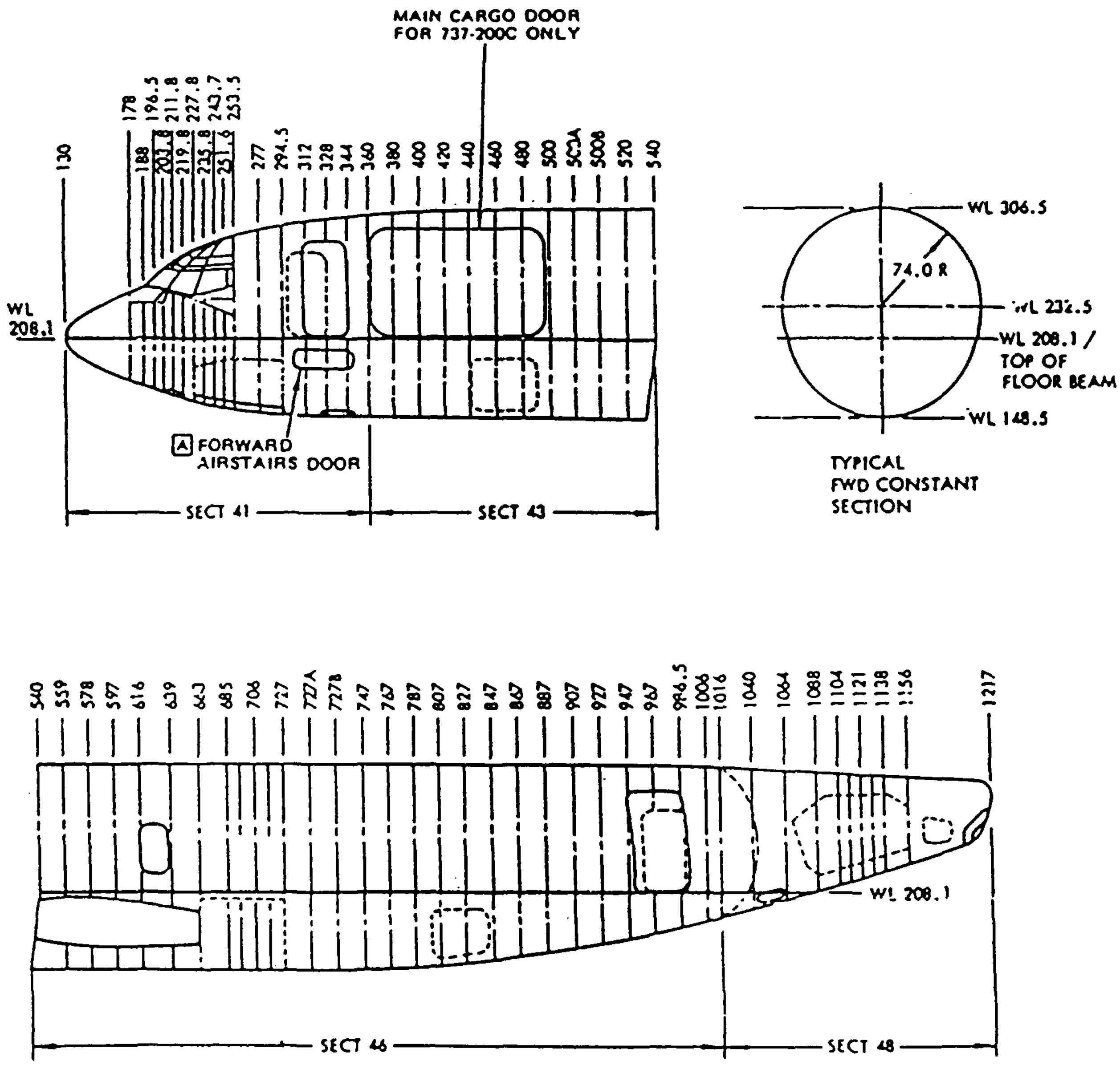


FIGURE B-2 : Fuselage Station Diagram for 737-200

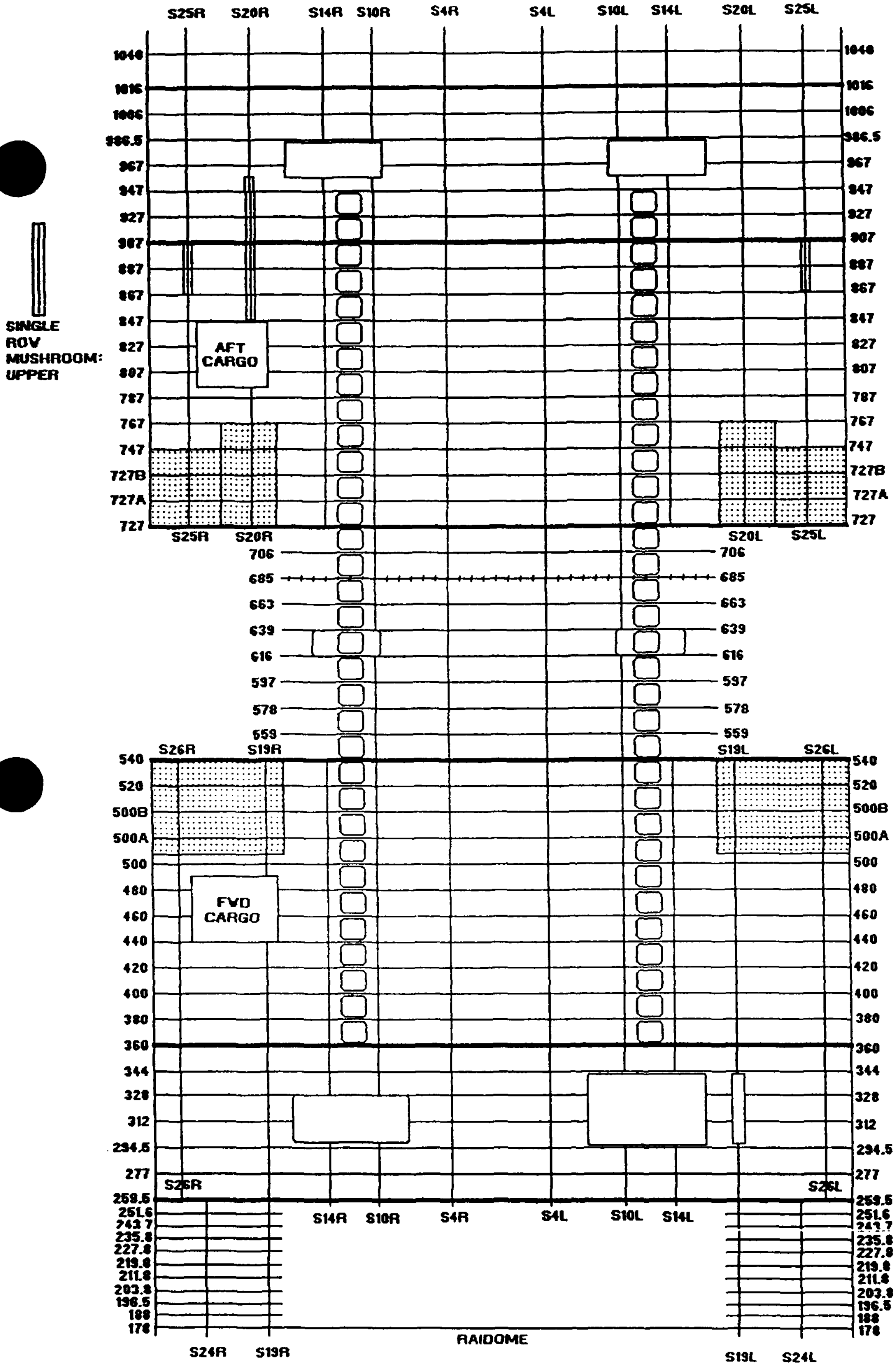


FIGURE B-3 : Fuselage Structure Layed Out to Show Fuselage Station and Stringer Grid (Used to Identify Inspection Locations)

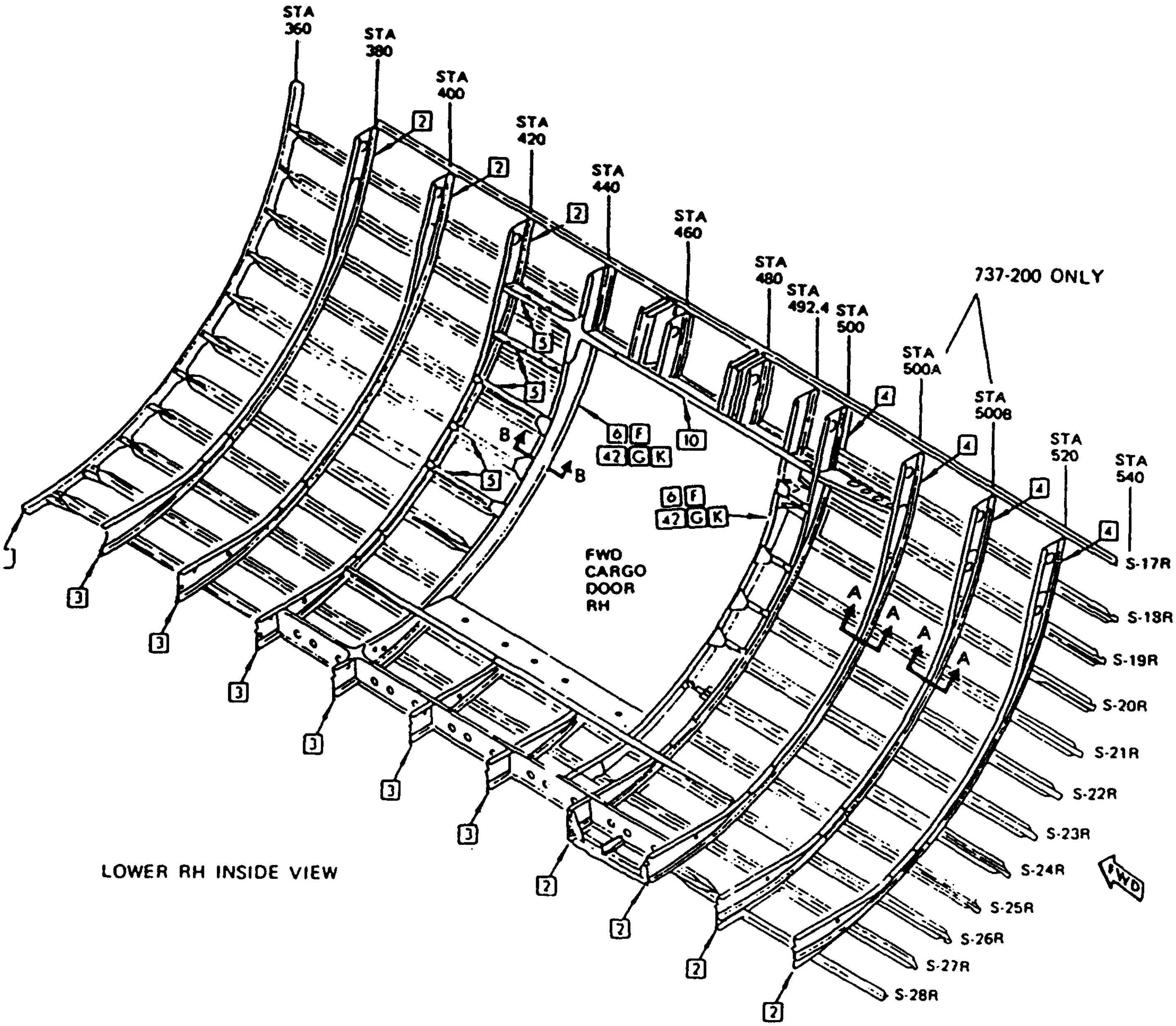


FIGURE B-4 : Sample Enlargement of Fuselage Section (section 43) Found in Structural Repair Manual and Used for Structure Identification

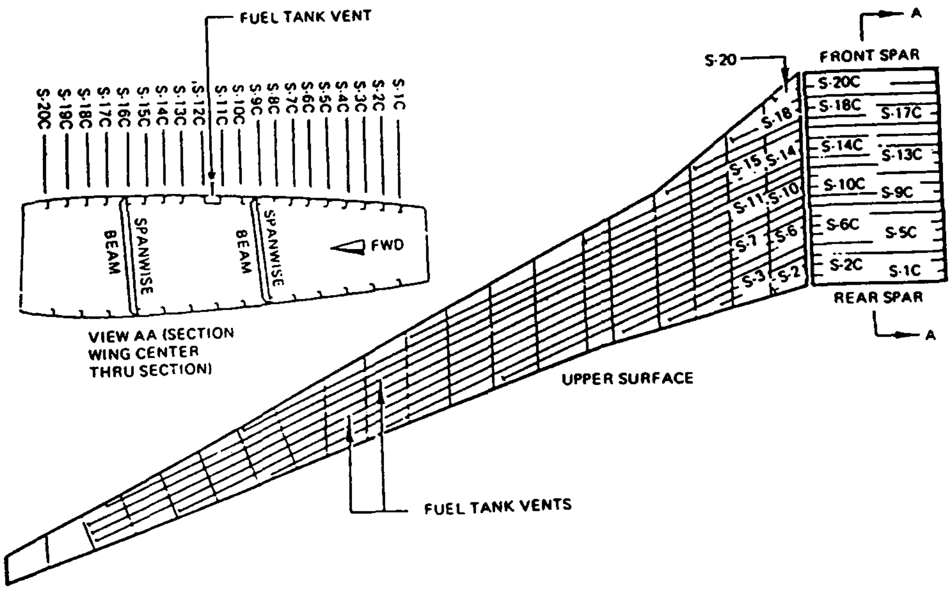


FIGURE B-5 : Wing Stringer Diagram

Documents Available at Review

Publication	Availability
Inspection Reliability of a Nortec-30 Eddy scan System	Sandia
Evaluation of Scanners for C-Scan Imaging in Nondestructive Inspection of Aircraft	Sandia
CASR Newsletter (periodic	CASR
CASR Publications List	CASR
FAA/NASA Workshop on the Application of Eddy Current, Radiographic and Ultrasonic Techniques to Aging Aircraft	FAA Tech Center
Proceedings of the First FAA Inspection Reliability Workshop, Sept 1&2 1993	FAA Tech Center
Reliability Assessment at Airline Inspection Facilities, Vol I - III	FAA Tech Center
Tech Note - Shearographic Inspection of a DeHaviland DHC-7	FAA Tech Center
NAARP 1993 Research Accomplishments	FAA Tech Center
NAARP Plan October 1993	FAA Tech Center
NAARP News (periodic)	FAA Tech Center

RESEARCH PROGRAM INITIATIVES

PROGRAM AREA: Validation and Technology Transfer

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	2.88		7	3.00				
FAA	4	2.50		4	3.00				
Mfgr	1	3.00		1	3.00				
Operator	2	3.00		2	3.50				
Researcher	4	2.75		4	3.50				
Other	2	3.00		2	3.50				
TOTAL	18	2.89	0.47	17	3.24	0.90			

PROGRAM AREA: Inspection Reliability and Visual Inspection

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	4	2.75		4	2.75				
FAA	4	2.50		4	2.00				
Mfgr	0			0					
Operator	2	3.00		2	3.00				
Researcher	3	3.00		3	2.83				
Other	2	3.00		2	3.75				
TOTAL	12	2.83	0.40	12	2.42	0.93			

PROGRAM AREA: Automation and Robotics

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	2	2.50		2	2.50				
FAA	2	2.00		2	2 50				
Mfgr	0			0					
Operator	2	2.00		2	3.00				
Researcher	2	2.50		2	3.50				
Other	1	2.00		1	3.00				
TOTAL	7	2.29	0.49	7	2.86	0.69			

PROGRAM AREA: Technologies for "law Detection

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	1	3.00		1	2.00				
FAA	2	2.50		2	2.50				
Mfgr	0			0					
Operator	1	2.00		1	3.00				
Researcher	2	2.00		2	4.00				
Other	2	2.75		2	3.25				
TOTAL	7	2.79	0.39	7	3.21	0.70			

PROGRAM AREA: Training and Information Dissemination

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	2	3.00		1	4.00				
FAA	2	2.00		2	2.50				
Mfgr	0			0					
Operator	2	2.50		0					
Researcher	2	3.00		1	3.00				
Other	1	2.00		1	4.00				
TOTAL	8	2.63	0.52	5	3.20	0.84			

VALIDATION AND TECH TRANSFER

TASK: Magneto-Optic Imager Validation at AANC

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	9	2.44		9	3.30				
FAA	6	1.62		6	2.83				
Mfgr	2	3.00		2	3.00				
Operator	3	2.67		3	3.17				
Researcher	7	2.43		7	3.43				
Other	3	3.00		3	3.17				
TOTAL	27	2.31	0.87	27	3.22	0.68			

TASK: Cost Benefit Analysis Protocol with MOI Example

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	2.89		10	2.70				
FAA	7	1.86		7	2.71				
Mfgr	2	2.5		2	3.00				
Operator	3	2.67		3	3.17				
Researcher	6	2.83		6	3.17				
Other	3	3.00		3	3.50				
TOTAL	26	2.62	0.70	27	3.00	0.97			

TASK: Assessment of Eddy Current Inspection Equipment

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	9	2.40		8	3.00				
FAA	6	2.33		6	3.17				
Mfgr	2	2.00		2	2.50				
Operator	3	2.33		3	2.83				
Researcher	6	2.83		6	3.25				
Other	2	2.50		2	3.50				
TOTAL	24	2.50	0.51	23	3.08	0.65			

TASK: Assessment of Scanners for C-Scan Imaging

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	2.80		8	3.63				
FAA	7	2.07		6	2.33				
Mfgr	2	2.50		2	4.00				
Operator	3	2.33		3	3.33				
Researcher	5	2.20		5	3.60				
Other	2	2.00		2	2.00				
TOTAL	25	2.34	0.62	22	3.18	0.96			

TASK: Technology Transfer Process and Implementation

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	3.00		7	2.57				
FAA	4	3.00		3	3.00				
Mfgr	2	3.00		0					
Operator	3	3.00		2	3.5				
Researcher	2	2.50		2	3.00				
Other	3	3.00		2	3.50				
TOTAL	18	2.94	0.24	13	2.85	1.14			

TASK: Self-Compensating Ultrasonics for DC9 Wingbox

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	3.00					8	2.00	
FAA	5	2.80					5	1.80	
Mfgr	2	3.00					2	2.00	
Operator	3	3.00					2	2.00	
Researcher	4	2.50					4	1.50	
Other	3	3.0					1	1.50	
TOTAL	21	2.86	0.36				19	1.76	0.54

CANDIDATE TECH TRANSFER ACTIVITIES

TASK: Dripless Bubbler and Low Frequency Ultrasonic Probe

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	9	2.39					9	1.44	
FAA	7	2.14					6	1.42	
Mfgr	2	2.25					1	1.50	
Operator	3	3.00					2	2.00	
Researcher	6	2.67					5	1.40	
Other	2	3.00					1	1.00	
TOTAL	25	2.52	0.57				22	1.45	0.58

TASK: Low Cost Photodensitomerter for X Ray Imaging

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	6	2.00					6	0.67	
FAA	5	1.40					5	1.00	
Mfgr	0						0		
Operator	1	2.00					0		
Researcher	4	1.75					2	0.50	
Other	1	3.00					1	1.50	
TOTAL	16	1.88	0.62				13	0.73	0.78

TASK: Probe Calibration and Standards

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	2.00					8	1.25	
FAA	7	2.29					5	1.57	
Mfgr	1	3.00					0		
Operator	3	2.00					2	2.00	
Researcher	6	2.17					4	1.25	
Other	2	2.50					1	1.50	
TOTAL	24	2.25	0.79				20	1.53	1.04

TASK: X-ray Backscatter for Corrosion Detection

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	9	1.33					9	0.33	
FAA	7	1.71					6	0.67	
Mfgr	2	1.50					2	0.00	
Operator	2	1.50					1	0.00	
Researcher	7	1.71					5	0.60	
Other	2	2.25					1	1.00	
TOTAL	25	1.54	0.68				21	0.43	0.75

TASK: Self Compensating Ultrasonics for DC9 Wingbox

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	2.75					8	2.00	
FAA	7	2.71					5	1.60	
Mfgr	1	3.00					1	1.00	
Operator	3	3.00					2	2.00	
Researcher	3	2.30					4	1.25	
Other	1	3.00					1	1.50	
TOTAL	21	2.71	0.56				19	1.71	0.56

TASK: Shearographic Inspection for Disbonds

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	7	1.86					9	0.88	
FAA	3	2.30					3	1.00	
Mfgr	0						0		
Operator	2	2.00					1	0.00	
Researcher	6	2.20					4	1.00	
Other	2	2.00					0		
TOTAL	18	2.06	0.64				15	1.20	1.32

TASK: Thermal Wave Imaging

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	2.56					8	1.40	
FAA	7	1.86					6	0.50	
Mfgr	1	2.00					1	0.00	
Operator	3	2.83					2	1.50	
Researcher	5	2.20					4	0.50	
Other	2	3.00					0		
TOTAL	23	2.28	0.69				19	0.89	0.81

TASK: Eddy Current Inspection Reliability Experiment

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	2.50		10	3.20				
FAA	6	2.83		5	3.60				
Mfgr	2	2.50		2	4.00				
Operator	2	2.75		3	3.67				
Researcher	7	2.43		7	3.40				
Other	2	3.00		2	3.50				
TOTAL	24	2.60	0.77	27	3.52	0.58			

TASK: Visual Inspection Program

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	2.88		7	2.14				
FAA	7	2.60		7	2.00				
Mfgr	2	3.00		0					
Operator	3	2.83		3	2.50				
Researcher	6	2.83		5	2.20				
Other	2	3.00		2	2.75				
TOTAL	24	2.81	0.48	21	2.29	0.73			

TASK: Computer Codes for Inspection Simulation

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	8	1.94		8	3.00				
FAA	5	1.80		5	3.00				
Mfgr	1	3.00		1	4.00				
Operator	3	2.67		3	3.67				
Researcher	6	2.17		6	3.08				
Other	2	2.00		2	1.75				
TOTAL	22	2.07	0.79	22	3.00	0.87			

TASK: Enhanced Visual Inspection for Corrosion using D-sight

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	9	1.16		8	1.50		1	1	
FAA	6	1.83		6	2.67				
Mfgr	1	2.00		1	2.00				
Operator	3	2.00		3	2.67				
Researcher	6	2.50		5	3.20				
Other	2	3.00		2	3.75				
TOTAL	24	1.94	0.89	21	2.52	1.09			

TASK: Enhanced Visual Inspection Tools for Airframes

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	6	2.50		6	2.83				
FAA	2	2.50		1	4.00				
Mfgr	2	2.50		1	2.00				
Operator	1	3.00		1	2.00				
Researcher	3	3.00		2	4.00				
Other	1	3.00		1	4.00				
TOTAL	13	2.62	0.65	10	3.30	1.06			

TECHNOLOGIES FOR FLAW DETECTION

TASK: Local Laser Based Ultrasonics

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	9	1.67		9	2.67		10	0.50	
FAA	7	1.71		7	2.50		7	0.50	
Mfgr	7	2.75		2	3.50		2	0.25	
Operator	2	1.50		2	2.25		1	0.00	
Researcher	7	1.86		7	2.71		6	0.33	
Other	2	2.50		2	3.25		1	1.00	
TOTAL	25	1.82	0.83	25	2.88	0.96	24	0.42	0.64

TASK: Self Compensating Ultrasonics Probe

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	2.70		10	3.50		10	1.55	
FAA	7	2.71		7	3.00		7	1.57	
Mfgr	2	2.50		2	3.50		2	1.00	
Operator	3	3.00		3	3.67		2	2.00	
Researcher	7	2.42		7	3.60		6	1.50	
Other	2	3.00		2	4.00		1	1.50	
TOTAL	27	2.70	0.47	27	3.48	0.64	25	1.56	0.57

TASK: Thermal Wave Imaging

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	2.35		10	2.90		9	1.22	
FAA	7	2.00		6	2.33		6	0.82	
Mfgr	2	2.50		1	4.00		2	0.75	
Operator	3	2.67		3	3.50		2	1.5	
Researcher	7	2.80		7	3.71		6	0.67	
Other	2	3.00		2	4.00		1	1.00	
TOTAL	27	2.44	0.63	25	3.10	1.04	22	0.91	0.80

TASK: Dual Band Infrared Imaging

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	1.40		10	2.90		9	1.11	
FAA	6	0.75		5	2.22		6	0.50	
Mfgr	2	1.50		1	2.00		1	0.00	
Operator	2	2.67		3	3.50		3	1.00	
Researcher	4	2.00		4	3.25		4		
Other	1	3.00		1	3.50				
TOTAL	23	1.93	0.73	21	2.95	0.85	21	0.81	0.81

TASK: Ultrasonic Characterization of Adhesive Bonds

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	2.60		10	3.50		10	1.40	
FAA	6	2.33		6	2.83		5	1.40	
Mfgr	2	2.75		2	4.00		2	1.00	
Operator	2	2.75		2	3.75		2	1.00	
Researcher	7	2.42		6	3.50		5	1.20	
Other	1	3.00		1	4.00		1	1.00	
TOTAL	24	2.54	0.57	24	3.44	0.71	23	1.26	0.69

TASK: Coherent Widefield Optical Imaging

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	9	2.00		9	3.11		9	0.72	
FAA	5	1.60		5	1.80		5	0.60	
Mfgr	1	2.00		1	3.00		1	0.00	
Operator	2	1.50		2	3.25		1	0.00	
Researcher	7	2.14		7	3.57		5	0.80	
Other	1	2.00		1	4.00		1	0.50	
TOTAL	22	1.95	0.58	22	3.02	1.22	20	0.60	0.77

TASK: Shearographic Inspection Modeling

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	2.00		10	3.00		9	0.55	
FAA	5	1.80		5	2.00		5	0.60	
Mfgr	1	2.00		1	3.00		1	0.00	
Operator	3	2.50		2	3.25		2	0.00	
Researcher	7	2.29		6	3.50		5	0.70	
Other	1	2.00		1	3.00		1	1.00	
TOTAL	23	2.09	0.67	22	2.93	1.12	20	0.53	0.75

TASK: Ultrasonic Lamb Wave Disbond Detection

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	2.20		9	3.11		10	0.95	
FAA	2	2.00		2	3.50		2	1.50	
Mfgr	2	2.50		2	3.50		2	0.75	
Operator	2	1.50		2	2.00		2	1.00	
Researcher	6	1.50		5	3.90		4	0.88	
Other	1	2.00		1	3.50		0		
TOTAL	20	1.95	0.69	18	3.14	1.03	17	0.85	0.84

TASK: Eddy Current Methods for Corrosion

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	3	2.67		3	3.33		3	1.67	
FAA	2	2.50		2	3.00		2	1.50	
Mfgr	1	2.00		0			1	0.00	
Operator	1	3.00		1	4.00		1	1.00	
Researcher	1	3.00		1	4.00		1	0.50	
Other	1	3.00		1	4.00		1	1.50	
TOTAL	7	2.71	0.49	6	3.66	0.82	7	1.14	0.75

TASK: Radiography for Corrosion Detection

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	3	2.00		2	2.50		2	1.00	
FAA	2	2.00		2	3.00		2	1.50	
Mfgr	1	2.00		0			1	0.00	
Operator	1	3.00		0			0		
Researcher	1	2.00		4	4.00		1	1.00	
Other	1	2.00		1	3.50		0		
TOTAL	8	2.13	0.64	5	2.90	0.89	5	0.80	0.83

TASK: Robotic Devices for Fastened Skins

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	1.80		9	2.50		8	0.38	
FAA	7	2.29		6	3.33		7	0.43	
Mfgr	2	1.00		2	2.50		2	0.00	
Operator	2	2.00		2	3.25		2	0.00	
Researcher	6	2.33		6	3.00		4	0.25	
Other	2	2.00		1	3.00		1	0.00	
TOTAL	25	2.08	0.86	23	3.07	0.77	21	0.29	0.56

TASK: Neural Nets for Wheel Inspection

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	1.80		10	2.50		9	1.33	
FAA	6	1.83		6	2.33		6	1.16	
Mfgr	2	1.50		2	2.00		2	1.25	
Operator	2	2.00		2	2.75		2	1.00	
Researcher	4	2.00		5	3.60		4	0.88	
Other	1	3.00		1	2.50		1	0.50	
TOTAL	23	1.96	1.07	23	2.74	1.33	21	1.10	0.83

TASK: Image Processing for X-ray

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	10	1.50		10	2.60		9	1.33	
FAA	7	1.86		6	2.75		6	.833	
Mfgr	2	1.00		2	2.50		2	2.00	
Operator	2	2.00		2	2.75		1	1.00	
Researcher	5	2.22		5	3.20		4	1.38	
Other	1	2.00		1	3.00				
TOTAL	24	1.92	0.93	23	2.87	0.93	19	1.18	0.77

TASK: Innovative Process for Technology Transfer

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	9	2.55		5	4.00				
FAA	4	2.75		4	3.50				
Mfgr	2	2.50		1	4.00				
Operator	2	3.00		0					
Researcher	6	2.83		6	3.58				
Other	3	3.00		1	4.00				
TOTAL	21	2.71	0.72	16	3.72	0.52			

TASK: Job Task Analysis/Visual Task Descriptors

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	7	2.86		6	3.50				
FAA	4	2.50		3	3.67				
Mfgr	1	3.00		1	2.00				
Operator	2	2.50		1	2.00				
Researcher	4	2.25		3	3.00				
Other	1	1.00		1	4				
TOTAL	17	2.65	0.49	14	3.21	0.89			

TASK: Aviation Inspection Training Course Development

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	7	3.00		6	3.67				
FAA	2	3.00		2	4.00				
Mfgr	2	3.00		2	4.00				
Operator	1	3.00		1	2.00				
Researcher	2	2.50		2	4.00				
Other	1	3.00		1	4.00				
TOTAL	12	2.92	0.29	11	3.82	0.60			

TASK: X-ray Training Software

	Priority			Grade			Tech Tsfr		
	responses	average	deviation	responses	average	deviation	responses	average	deviation
AANWG	6	2.67		7	3.57				
FAA	3	2.66		3	3.66				
Mfgr	2	3.00		2	4.00				
Operator	1	3.00		1	4.00				
Researcher	2	2.50		2	4.00				
Other	2	2.50		1	4.00				
TOTAL	12	2.71	0.45	13	3.77	0.44			

Goals of Program **Program Element**

Good general overview. There should have been better direction as to what is expected from evaluators. Does the FAA have control with established priorities or is
guidance needed from technical community?
Guide to sheets.
Reasonable goals.
No talks about goals. More on grading sheets and way to use them.
-
Short and sweet (the program presentation, that is.
Short and direct-good.
Sufficient in view of Seher's presentation.
-
-
-
Without participating regularly in your meetings, it is difficult to understand how all the groups interact, but it is clear from your goals and approach that you are headed in the right direction and looking at the right things. But, a "user friendly" interface, preferably human, would be beneficial. Maybe someone is already in this position. For example if I want to transfer some of the technology I have seen here to industry, how do I do it? Is there a written roadmap I can follow, or someone I can call? If there are not now, there should be in the future, individuals who are experts in technology transfer. Assign someone to me so I can take this technology and get it to our customers who need it. Someone should be able to interface in and out of this research network without having to know how it all works.
Clear, straightforward.
Understood.
-
Ok "Thank you" was good.
-
-
Much improved focus.Still needs work in identifying owners of technology <u>if</u> developed.
-
-
-
Overall program seems to have several worthwhile projects however no clear end result. Introduce new technologies? Improve overall inspection reliability? Prevent reoccurrence of Aloha incident? When do we know we've succeeded? Feel there is significant room for improvement in existing processes and procedures and that some funding should be directed to OEM's/operators to address these issues. Support/research could then be solicited from academic/scientific community to overcome specific problems encountered.
-
-
-
-
-
-

Excellent in conveying tech transfer role. Perhaps he should have had a better grasp of what needs to be done in this area. Who is expected to pay for it and where does the leadership come for the tech transfer project?
Review & comment.
Good, coherent program. Organized in a well coordinated manner. Looks like a mature program.
Put program in perspective.
-
Well organized program...taxpayers should be happy. Feedback felt dated...did it get to the corresponding researchers more quickly?
He definitely made it clear that the NAARP's products are directed towards progress, not research done in a vacuum.
-
Very good summary.
-
-
Chris is an effective speaker - Lots of information - Rapid pace. "Comments slides" - Unclear who made comments - Important to know who made comment as well as what the comment is. Commuter comment on need for training still valid after 4 years - need videos - need them now.
Without participating regularly in your meetings, it is difficult to understand how all the groups interact, but it is clear from your goals and approach that you are headed in the right direction and looking at the right things. But, a "user friendly" interface, preferably human, would be beneficial. Maybe someone is already in this position. For example if I want to transfer some of the technology I have seen here to industry, how do I do it? Is there a written roadmap I can follow, or someone I can call? If there are not now, there should be in the future, individuals who are experts in technology transfer. Assign someone to me so I can take this technology and get it to our customers who need it. Someone should be able to interface in and out of this research network without having to know how it all works.
Clear, straightforward. Appreciate no-nonsense approach. Direct to the real issue.
Excellent.
What impact does the researchers need for patents, copyrights and regulations have on tech trans and how des FAA address this impact?
Very good.
Liked the review of comments -- shows FAA NAARP is really responding to advice from Advisory groups.
-
Great improvement. Still suffers from pork barrel.
-
-
-
Overall program seems to have several worthwhile projects however no clear end result. Introduce new technologies? Improve overall inspection reliability? Prevent reoccurrence of Aloha incident? When do we know we've succeeded? Feel there is significant room for improvement in existing processes and procedures and that some funding should be directed to OEM's/operators to address these issues. Support/research could then be solicited from academic/scientific community to overcome specific problems encountered.
Too long on material that should have been distributed i.e., response to part comments.
-
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-
-

Excellent in conveying tech transfer role. Perhaps he should have had a better grasp of what needs to be done in this area. Who is expected to pay for it and where does the leadership come for the tech transfer project? Overall program description was good. Description of specific goals was effective. Coverage of best projects was effective.
Very busy view.
I believe tech transfer requires a proactive effort. It has to be part of the mission of the research projects (part of the scope of work). Otherwise it is too serendipitous.
Appropriate emphasis on cost/benefit and technology transfer.
Not really explained in C. Seher's talk.
Well organized program...taxpayers should be happy. Feedback felt dated...did it get to the corresponding researchers more quickly?
Tech transfer is more than just listening to the "pull" of the industry. It can also involve anticipating the needs of the industry before industry does.
-
Message for Tech Transfer was clear. However, I believe that <u>meaning</u> of "Tech Transfer" should is it commercialization by private firm? If so, technical viability and cost benefits do not guarantee commercial success. If not, who pays to transfer technology to would be users?
-
-
Not clear when overall program approach ended and tech transfer began.
Without participating regularly in your meetings, it is difficult to understand how all the groups interact, but it is clear from your goals and approach that you are headed in the right direction and looking at the right things. But, a "user friendly" interface, preferably human, would be beneficial. Maybe someone is already in this position. For example if I want to transfer some of the technology I have seen here to industry, how do I do it? Is there a written roadmap I can follow, or someone I can call? If there are not now, there should be in the future, individuals who are experts in technology transfer. Assign someone to me so I can take this technology and get it to our customers who need it. Someone should be able to interface in and out of this research network without having to know how it all works.
Good to review previous input and real status.
Good when does dream become reality!
Would like to see clear delineation between "core technology" and tech transfer. Core tech never transfers but provides basis for future widgets. How does the 15% long term relate to this?
Very good.
-
-
Weak, weak - Strong discipline required to identify "who wants it?" - <u>Before</u> program is funded.
-
-
-
Increase Beta sight testing would be helpful in Technology Transfer, however operators have limited resources/ manpower to support this. Again, funding directed to this area would be helpful.
Really wasn't done. Just one viewgraph.
-
-
-
-
-

No priorities established/Lip service to cooperation with validation center. No real emphasis or understanding of tech transfer process; no evidence of communication of goals to tech staff.
Your guide.
Excellent overview of the program at CASR
Too detailed on examples. Leave that to presenters.
Ave all candidate technologies covered?
Useful survey both administrative /organizational and technical. Might distribute a bibliography of tech reports etc.
Good-very concise and understandable presentation of very technical projects. Used the term "tech transfer," but didn't really address the issues of tech transfer.
-
Technical descriptions were good.
-
-
-
Without participating regularly in your meetings, it is difficult to understand how all the groups interact, but it is clear from your goals and approach that you are headed in the right direction and looking at the right things. But, a "user friendly" interface, preferably human, would be beneficial. Maybe someone is already in this position. For example if I want to transfer some of the technology I have seen here to industry, how do I do it? Is there a written roadmap I can follow, or someone I can call? If there are not now, there should be in the future, individuals who are experts in technology transfer. Assign someone to me so I can take this technology and get it to our customers who need it. Someone should be able to interface in and out of this research network without having to know how it all works.
Excellent overview/Sampler of presentations to come. Appreciate the focus on synergy between CASR project and AANC project.
-
Good summary of what we can expect in task briefings. Need to see actual technology transferred - airline "X" is using "Grey's" X-ray to inspect the whatsit.
Audence concensus seemded to be that it was busy?
Good to see CASR/Industry interaction.
Presentation too long. Went into details which are repeated in the technical talks of following days.
Dripless bubbler - not new - how is it better - homework? XR SIM is not unique.
-
-
-
Good.
I missed.
Too much like a travelogue, everything he said was repeated later. To much deja vu.
Good overview at what Iowa State is working on. Some significant new technique.
-
-
-

CASR Project - Overall Program Element

Good review of progress.
Can now press cycle 737. Several mfrs. validation trends. POD Exp.--results? Final draft ant. 737 Stimu. test MOI validated. Seamer animants. Developing Database of trials, do they agree? Who has access? Boeing 737 cycles, Coor. C& D cks. FAA Tech development process now has operators at end product with no review process at beginning.
It appears that the AANC is definitely up and running and making progress.
-
C-D check as boreline may not be sufficient and iwll do little for tech. The 737 maybe corroding as we speak.
Good progress. Not clear what is the mix between proactive ("you must come to Albuquerque") and passive ("you can come to Albuquerque").
Better than above (speaker) because he showed actual evidence of tech transfer activities-especially in the joint activities (ie-specimen library). These activities appeared to be more helpful to the industry.
-
Very good summary of project/activities.
-
-
Good overview - they have been busy! Very clear overview.
Without participating regularly in your meetings, it is difficult to understand how all the groups interact, but it is clear from your goals and approach that you are headed in the right direction and looking at the right things. But, a "user friendly" interface, preferably human, would be beneficial. Maybe someone is already in this position. For example if I want to transfer some of the technology I have seen here to industry, how do I do it? Is there a written roadmap I can follow, or someone I can call? If there are not now, there should be in the future, individuals who are experts in technology transfer. Assign someone to me so I can take this technology and get it to our customers who need it. Someone should be able to interface in and out of this research network without having to know how it all works.
Photo test images really help gain an appreciation for various programs. Excellent overview/Sampler of presentations to come. Appreciate the focus on synergy between AANC project and CASR project.
Ok, but missing hidden non routine (sparks) by not having mech remove rivets and opening part to expose support beams i.e., 9 to, L.G. S-18A etc.
Good recovery on the flashlight debacle.
-
AANC really starting to show its value -- number of activities over past year is impressive. Big question concerning when to characterize B737 to validate various findings.
Good overview of work at AANC.
Why are SAIC and Harwell in this pork barrel task?
-
-
-
Good.
OK!
-
-
-
-
-

Priority	Grade	Comment
		AANWG
3	3	It is necessary to have a universally understood set of steps defined in tech transfer process. Perhaps a workshop for PI's and publication of material in NAARP News.
3	4	Lockheed/Delta (Dick Johnson) use of Composite (Textron) patches around door. Sandia stran wrapping bringing NDI and stress exp. together stress analysis of repairs. Library -- good for mfr. & FAA.
3	-	-
-	-	-
3	1	Very weak. Who wants the technology, buys the idea, What is prior art? Why is it better? Rationale is missing.
3	4	Seems to be on track.
3	4	-
-	-	Presentations - 20 min talk/10 min question/cut off-keep to schedule.
3	3	-
		FAA
2	2	-
-	-	Did not really see much presented to judge overall management of each RPI nor on management of each task.
-	-	-
-	-	-
3	2	-
3	4	-
2	4	Pat was interrupted by questions - Lost continuity - Should have saved questions till end. Didn't understand questions - so didn't follow answers! Validation Center important. Need high priority on purchase of Fairchild Metro, Medium Priority otherwise.
-	-	-
		Manufacturer
3	3	Validating and transferring the technology must always be of high priority if we are to do more than research just for the sake of research. Funding experts could be assigned to projects to help us get the "bridge" dollars needed to go from laboratory to marketplace.
		Operators
3	4	Research without tech transfer is interesting from an academic standpoint only. Research that leads to tech transfer saves money, increases safety and efficiency and is also even more interesting academically. This is an essential link. We who maintain aircraft need this.
-	-	-
-	-	-
		FAA Sponsored Researchers
2	3	Recommend specific efforts be made to attract companies for commercialization.
3	4	-
-	-	-
-	-	-
-	-	-
3	4	-
3	3	-
		Other
-	-	I am not sufficiently knowledgeable on the specific items to give a fair assessment. General comment on the technical presentation is that the format should be reconsidered to address technology transfer issues more directly. Presentations are generally in usual research progress reporting. If TT is real goal, then discussions should directly include user(s) inputs/candid consideration of difficulties, deficiencies etc., and what possible solutions. If commercialization is goal, then some kind of strategic partnership should be established early during research project to take advantage of industry expertise. Successful commercialization requires cooperation of technology, manufacturing and marketing from inception.
3	3	-

Priority	Grade	Comment
		AANWG
3	3	Good description of studies. Work by Smith, Brewer, Spencer was not described as an integrated whole relationship to rulemaking not explained.
-	-	This part of the program should have been left out. No comment covered same material on Wednesday.
-	-	-
-	-	-
3	0	Hold for plan.
-	-	Wasted afternoon. All efforts duplicated today (Wednesday).
-	-	-
-	-	Presentations - 20 min talk/10 min question/cut off-keep to schedule.
3	3	-
		FAA
2	2	-
-	-	Did not really see much presented to judge overall management of each RPI nor on management of each task.
-	-	-
-	-	-
3	2	-
2	2	-
-	-	-
3	2	Can you find cracks small and faster. User friendly.
		Manufacturer
-	-	-
		Operators
3	3	Although very important to assess reliability of various inspections, the results from one assessment may not translate well to other applications, even for the same book methodology. Extrapolation of results should be done carefully.
-	-	-
-	-	-
		FAA Sponsored Researchers
3	2.5	Except for the special flashlight, it didn't seem like much is happening in the Visual Insp. areas. There appears to be some disagreement on definitions of Insp. Reliability, but ECIRE was good.
-	-	-
-	-	-
-	-	-
-	-	-
3	3	-
3	3	-
		Other
-	-	I am not sufficiently knowledgeable on the specific items to give a fair assessment. General comment on the technical presentation is that the format should be reconsidered to address technology transfer issues more directly. Presentations are generally in usual research progress reporting. If TT is real goal, then discussions should directly include user(s) inputs/candid consideration of difficulties, deficiencies etc., and what possible solutions. If commercialization is goal, then some kind of strategic partnership should be established early during research project to take advantage of industry expertise. Successful commercialization requires cooperation of technology, manufacturing and marketing from inception.
3	3.5	-

Priority	Grade	Comment
		AANWG
3	2	Not reported. Many of the automated detection techniques appear to be candidates for the CMU crawler. These should be evaluated in terms of their effectiveness when combined with robotic locomotion.
-	-	This part of the program should have been left out. No comment covered same material on Wednesday.
-	-	-
-	-	-
-	-	-
-	-	Wasted afternoon. All efforts duplicated today (Wednesday).
-	-	-
-	-	Presentations - 20 min talk/10 min question/cut off-keep to schedule.
2	3	-
		FAA
-	-	-
-	-	Did not really see much presented to judge overall management of each RPI nor on management of each task.
-	-	-
-	-	-
2	2	-
2	3	-
-	-	-
-	-	-
		Manufacturer
-	-	-
		Operators
2	3	Automation/Robotics efforts need to offer significant improvements in time savings, reliability and cost. They also should tend toward greater simplification as much as possible.
-	-	-
-	-	-
		FAA Sponsored Researchers
3	4	I think we are making good progress. Perhaps I'm biased.
-	-	-
-	-	-
-	-	-
-	-	-
2	3	-
-	-	-
		Other
-	-	I am not sufficiently knowledgeable on the specific items to give a fair assessment. General comment on the technical presentation is that the format should be reconsidered to address technology transfer issues more directly. Presentations are generally in usual research progress reporting. If TT is real goal, then discussions should directly include user(s) inputs/candid consideration of difficulties, deficiencies etc., and what possible solutions. If commercialization is goal, then some kind of strategic partnership should be established early during research project to take advantage of industry expertise. Successful commercialization requires cooperation of technology, manufacturing and marketing from inception.
-	-	-

Priority	Grade	Comment
		AANWG
3	3	There was little discernable emphasis on the provisions of Smiths requirements document which was a good attempt to arrive at an applications need driven program. How were requirements prioritized?
-	-	This part of the program should have been left out. No comment covered same material on Wednesday.
-	-	-
-	-	-
-	-	-
-	-	Wasted afternoon. All efforts duplicated today (Wednesday).
-	-	-
-	-	Presentations - 20 min talk/10 min question/cut off-keep to schedule.
-	-	-
		FAA
-	-	-
-	-	Did not really see much presented to judge overall management of each RPI nor on management of each task.
-	-	-
-	-	-
3	2	-
2	3	-
-	-	-
-	-	-
		Manufacturer
-	-	-
		Operators
3	3	Need less emphasis on Boeing-Type lap joints and more efforts aimed at detecting hidden corrosion and small (<.60") cracks. Corrosion underlying complex internal structure is a serious, expensive problem to detect (DC9 wing good example). These need effort.
-	-	-
-	-	-
		FAA Sponsored Researchers
3	4	The right kinds of technologies are being pursued.
-	-	-
-	-	-
-	-	-
-	-	-
3	4	-
-	-	-
		Other
-	-	I am not sufficiently knowledgeable on the specific items to give a fair assessment. General comment on the technical presentation is that the format should be reconsidered to address technology transfer issues more directly. Presentations are generally in usual research progress reporting. If TT is real goal, then discussions should directly include user(s) inputs/candid consideration of difficulties, deficiencies etc., and what possible solutions. If commercialization is goal, then some kind of strategic partnership should be established early during research project to take advantage of industry expertise. Successful commercialization requires cooperation of technology, manufacturing and marketing from inception.
2.5	3.5	-

Priority	Grade	Comment
		AANWG
-	-	-
-	-	This part of the program should have been left out. No comment covered same material on Wednesday.
-	-	-
-	-	-
-	-	-
-	-	Wasted afternoon. All efforts duplicated today (Wednesday).
3	4	-
-	-	Presentations - 20 min talk/10 min question/cut off-keep to schedule.
3	-	-
		FAA
-	-	-
-	-	Did not really see much presented to judge overall management of each RPI nor on management of each task.
-	-	-
-	-	-
2	2	-
2	3	-
-	-	-
-	-	-
		Manufacturer
-	-	-
		Operators
2	-	Not able to evaluate/comment on due to my lack of familiarity with industry/FAA processes for these issues.
-	-	-
-	-	-
		FAA Sponsored Researchers
3	-	-
-	-	-
-	-	-
-	-	-
-	-	-
3	3	-
-	-	-
		Other
-	-	I am not sufficiently knowledgeable on the specific items to give a fair assessment. General comment on the technical presentation is that the format should be reconsidered to address technology transfer issues more directly. Presentations are generally in usual research progress reporting. If TT is real goal, then discussions should directly include user(s) inputs/candid consideration of difficulties, deficiencies etc., and what possible solutions. If commercialization is goal, then some kind of strategic partnership should be established early during research project to take advantage of industry expertise. Successful commercialization requires cooperation of technology, manufacturing and marketing from inception.
3	4	-

Priority	Grade	Comment
		AANWG
2	4	The study is complete. MOI has been studied to death. It is now one of several BC based imaging systems for which applications should be defined, and the systems validated.
0	4	Task completed for cracks -- Possible work to do on corrosion. MOI 13% less time than slider. Vanessa Brechling, Cost/Benefit, develop a model, handbook.
3	3	High priority for validation process, not for MOI in particular (already happening). Reliability (POD) assessment is key - must be cost effective and valid for field applications.
3	3	-
2	2	Not well prepared. I want much more data on reference set-up (calibration) before publication.
3	4	Well documented, complete.
3	4	-
3	3	Presentation should have been given after EC. Reliability report. Much lost time on reliability protocol as opposed to tech transfer. Times should reflect uncracked structure--more likely encountered. I would be careful to assume strict POD data without assessment of crystal variability. Standards help to compensate for equipment variability in EC.
3	3	Accept validation for corrosion assessment. Validation for crack detection complete.
		FAA
-	-	-
-	-	-
1	2	Top concern of validation was cost benefit, which is important but size of flaw is the priority. The MOI was not a good example - because only cost benefit was achieved - no increase safety.
3	3	Need to explore the possibility of finding smaller cracks, 0.02" - 0.04".
2	3	-
2	4	-
1	2	Nothing convinced me that it will be a major method for commuters - Expense, training, etc. may be too high for them. Good program should continue - just not commuter material.
1	3	Large NED 2 people, must verify strip print?
		Manufacturer
3	3	Would have liked a lot more detail. Maybe more separation in the information between scanning and validation. MOI is also a substitute for standard pencil probe. I don't think paint is an issue between standard ET and MOI. I think validation is of higher importance than assessment since the manufacturer will still have to assess and pick the equipment but the FAA will have to bless its use. Cost is important in order to get support for new technologies and systems. But, of course, when it comes to safety of flight, the cost issue diminishes in the short term.
		Operators
2	3	Value of MOI, since it's apparently no more reliable than scan probe eddy current, is that it is much easier to train somebody new to the technique than it is with eddy current. Should also evaluate it relative to eddy current with non-experienced inspectors.
-	-	-
3	3.5	Audience was interested.
		FAA Sponsored Researchers
2	4	-
3	4	Questions on calibration consistency.
3	3	-
1	2	Skeptical about the method and evaluation process; nevertheless, it is important to learn how to do these evaluations.
2	3	Good thorough method for assessing reliability.
3	4	-
3	4	-
		Other
3	3.5	Overall methodology was very good. Presentation should more clearly designate MOI/EC curves; cracks measured from shank; the times should be broken down into inspection time and verification.
2.5	3	Gather more field data and experience under uniform procedures between facilities. Need setup calibration (despite what builders says about not needing!

Priority	Grade	Comment
		AANWG
3	3	Study is good. Service bulletin variables should be tabulated. Results should be presented in graphic form. Data should have been presented in graphic form.
3	4	Outline useful to operator for justification. Comparison was enlightening.
3	3	Assessment of "Risk" (consequence of missing flaws) has not been considered. Liability suits have driven many changes in industry - should this be considered?
3	3	This is a very difficult procedure. The credibility of the results will be questionable. All the figures for the analysis need to be given for it to be of use.
3	0	Not qualified to do analysis. I want no judgement value applied by people who are not part of the core competing.
3	4	The effort put into this analysis is great but actually the airlines would lump values together and make a decision on speed of inspection and reliability.
3	4	-
2	2	Priority 1 to develop protocol to do cost analysis, priority 3 as it applies to MOI. Additionally, paint need not be removed to do a reliable EC inspection. Heads up display or other improvements to assist single operator operation is worthwhile. C-grade-More presentation on cost analysis example. Walk through.
2	3	Establish protocol will be helpful - however the biggest difficulty lies in obtaining information on variables such as total man hours, number of present and future applications, total applicable airc[illegible] etc.
		FAA
3	1	Too much apple pie. Too much detail. Essentially not relevant to the topic.
-	-	Sounds like a good idea to do this.
1	3	Cost benefit is increased for the operator - where is the increase in safety?
3	3	Would it be possible to calculate an "allowable cost" for a presumed instrument that could find significantly smaller cracks based on the benefits that would accrue from that capability?
2	3	-
2	3	-
1	4	Analysis done!- File for Economic Analysis for AD NPRN if ever needed.
1	2	Only before I see time, suspect data, need better test bed.
		Manufacturer
3	4	Good job on an important issue. Your involvement in this issue and the development of good cost benefit analysis will help our customers purchase better inspection systems.
		Operators
3	4	Technique of cost-benefit analysis as presented is more valuable than specific applications/example. Sensitivity involved still leaves final "call" up to engineering judgement. An important tool, but still ultimately settles on judgement of operators.
-	-	Should the protocol be reviewed by APO in Washington headquarters? Net present value with what interest rate? Don't brief this till you have better handle on what to estimate.
3	2.5	NUTC could use 3 in house maintenance person on an "as needed" basis.
		FAA Sponsored Researchers
3	4	Probably would benefit from more interaction with airline operators.
3	4	-
3	3	Some of cost benefit analysis should be applied to programs before they get as far as MOI.
3	2	It is critical that credible cost/benefit methods be developed. It appears that the present work is not well connected to the industry.
-	-	-
2	3	-
3	3	Get Airline input on cost/benefit. Ask them how they would do it differently (If they'll tell you. How will you address differences in POD in future analyses if it becomes important?
		Other
3	3.5	Overall method appear to be good. I'm not sure based on experience, that decisions are made by users based on cost benefit analysis without other intangibles. How can these be tailored into evaluation? Overall evaluation and comparison of MOI should include template results since these are preferred by some organizations. Time for verification of MOI and sliding probe defect calls should be accounted for to give time comparison since under actual inspection, there are much fewer defect calls.
3	3	Good concepts--learning curve--need more study and second example to broader generic scope of capability.

Priority	Grade	Comment
		AANWG
3	3	First good exposure of results of this unique and excellent program. Some minor problems with draft report. Well presented. Conclusions should be more comprehensive.
2	3	Operators have been doing these inspection, results show they are pretty good.
2	3	EC evaluation is important but other technology warrants attention on equal plane (i.e. UT, enhanced visual etc.)
3	-	- (Added on comment -- why is the pulsed eddy current system not being considered for immediate transfer?
-	-	Not reviewed
3	3	Surface cracks were evaluated but what about 2nd and 3rd layer. To make this type of instrument cost effective it must be useful for something other than surface cracks.
2	3	-
2	3	It seems to be a cost effective approach to assess surface inspections. Similar systems (Bolt Hole, disbond) should be set up for other technologies.
2	2	Scope should be expanded - additional equipment should be assessed. Will this be a continuing program "consumer reports".
		FAA
3	4	Honest presentation.
-	-	-
2	2	-
2	4	-
2	3	-
3	4	-
-	-	-
2	2	-
		Manufacturer
2	2	Standardized calibration and reference standards should be used throughout the study.
		Operators
2	3	Difficult for me to evaluate grade in this case, because I'm not sure what application is driving it. Value relatively to what other technique?
-	-	-
3	3.5	TOGAA wants to know capabilities of inspection equipment in market place.
		FAA Sponsored Researchers
3	3	ECIRE was good. It may be beneficial to do some experiments to calibrate results with actual aircraft inspections. In this way prove validity of the study.
3	3.5	-
3	4	-
2	3	With a test flaw rate of 20% the inspector expects to find many flaws; in the field he expects to find few. How are the statistics adjusted to compensate?
-	-	-
3	3	-
3	3	-
		Other
-	-	Frankly, I believe Nortec Eddy Scan would be more cost effective for <u>subsurface</u> inspection.
3	4	-

Priority	Grade	Comment
		AANWG
3	4	Good consumer report needed by industry. Continuing need for.
2	3	Information is not new. Present usefulness questionable.
2	2	Good point made about how well the system detects flaws -- this was not a criteria for this analysis -- should this be a criteria?
3	-	-
3	2	Need advance agreement on analysis/rating procedures.
3	4	Complete, write report.
3	4	-
3	4	Well focused effort - good deliverable, worthwhile effort - despite all the discussion in the meeting. The information is useful to industry. Why is everyone building their own scanning systems? -- Ref. Sandia Report. Sandia getting ARPA money form Holographic - Can this cause a conflict of interest?
3	4	Priority? This project seems complete unless new scanners or improvements to existing scanners are assessed on a continuous basis.
		FAA
3	4	Good solid effort.
-	-	-
1	1	What's the point - scanners - which one detects the smallest defect for safety reasons.
3	-	-
2	3	-
2	3	-
2.5	2	Automated scanners for <u>any</u> inspection method are valid. It needs to be adaptable to smaller radius (commuter) applications.
1	1	Did not get relevance to real tie inspection on in maintenance aircraft.
		Manufacturer
2	4	Very thorough job. This type of information can be a great time and cost saver when it comes to purchasing hardware. Good organization and presentation of data. I think you are finished on this unless you want to update your list every year or so.
		Operators
2	3	Useful to those interested in scanners, but hard for me to evaluate, once again, without a sense for motivating need. Researchers need most.
-	-	-
2	3	Task complete - customer feedback required if more work required.
		FAA Sponsored Researchers
2	4	Thorough work.
-	-	-
2	3	Not quite comprehensive assessment.
2	4	A terrific term paper; I'm not sure I want to see it turn into a career (but it could be repeated every few years).
-	-	-
2	4	-
3	3	-
		Other
-	-	-
2	3	Should evaluate all scanners developed--not limited to vendors that came forward. For example, Southwest Research built mike-bar system to WL/ML (ARIS). Works well in field.

Priority	Grade	Comment
		AANWG
3	2	Each project needs its own tech transfer plan and a schedule for accomplishment. These plans should then be prioritized.
3	4	This type work is coincidental with need.
3	2	Good point made by MOI manufacturer about marketing -- how is the tech transfer plan addressing this?
-	-	-
3	0	Totally incoherent presentation. The wrong player.
-	-	-
3	4	-
3	-	Well defined problem - good for the program DC-9 Wing Box.
3	3	Overall program seems to have several worthwhile projects however no clear end result. Introduce new technologies? Improve overall inspection reliability? Prevent reoccurrence of Aloha incident? When do we know we've succeeded? Feel there is significant room for improvement in existing processes and procedures and that some funding should be directed to OEM's/operators to address these issues. Support/research could then be solicited from academic/scientific community to overcome specific problems encountered.
		FAA
3	3	-
-	-	-
-	-	-
3	-	-
3	2	-
3	4	-
-	-	-
-	-	-
		Manufacturer
3	-	-
		Operators
3	4	Most difficult yet most important part. Best effort yet to do this
-	-	-
-	-	-
		FAA Sponsored Researchers
-	-	Missed this.
?	?	-
-	-	-
-	-	-
-	-	Very good evidence of work with the commercial industry.
3	3	-
2	3	-
		Other
3	-	I think the wing box application is a good example how tech development and transfer can benefit from early alliance with potential user (NWA). Otherwise some development end up being solutions looking for problem. Here again definition of Tech Transfer is important.
3	3	-

Priority	X-fer	Comment
		AANWG
3	2	Well prepared presentation.
3	2	If it works give it a try.
?	2	Took a while to find an application but seems to be on its way now – success story? (Needed Northwest and Douglas to get it going.)
3	2	The large cost savings of this technique justifies its high priority. The airlines and OEM's require this kind of support or they are going to become disinterested in the program.
3	-	Needs considerable help in design of experiment.
3	2	Northwest Airlines has > 100 A/C to inspect. If an alternate means of compliance, if possible, should be expedited.
3	2	-
3	2	Should coordinate activities with AANC C-scan imaging program. Does flat bottom hole and EDM truly represent real structure? Does stuffing corrosive product represent sandwiched corrosive product that has never been removed? Hard to believe sealant thickness variations don't affect inspection (if I understand technology correctly).
3	2	Providing AMDC is approved.
		FAA
3	2	-
-	-	-
2	1	Labor benefit, time for inspection accomplishment - no increase or decrease in safety. A very promising technique. Northwestern need to increase development of this technique.
-	-	-
3	2	-
3	2	-
-	1	80 hrs. vs 800 hours justifies going on with validation and <u>certification</u> as an alternate means of compliance. <u>If it works</u>. FY 95 may be aggressive.
3	-	Loads or variables and unknowns need exact science probe unscanned area (impt).
		Manufacturer
3	2	Very important for our customers. Good job!
		Operators
3	-	Impressive development of this technique to a specific application. Method and software may be very valuable in other similarly inaccessible locations. USCG has areas on our aircraft similar to this and DC10 span cap/strap.
-	-	-
3	2	Further O2 validation effort required for go/no go criteria.
		FAA Sponsored Researchers
2	2	Straightforward acoustic technique that looks easy to implement.
3	2	SB, AD. Northwest Airlines pull essential. Corrosion & corrosion cracking.
?	-	-
?	?	I am baffled by what this is a government sponsored university research project; it looks like a task for a good NDI technician. There must be something hard about it that I am missing.
-	-	Nice to see researcher-industry interaction. Why is the manufacturer hesitant?
3	2	-
2	0	Looks very susceptible to noise when image processing. I imagine many misses and false calls, event technicians being able to rerun and get different results (i.e., limited repeatability). Do a blind study of several parts with real corrosion flat bottom holes are much easier to call than the gradual changes associated with real corrosion. What is scatter of materials/thicknesses in what about local changes in slope? (see drawling--How will these two signals be displayed and interpreted?
		Other
3	-	I think the wing box application is a good example how tech development and transfer can benefit from early alliance with potential user (NWA). Otherwise some development end up being solutions looking for problem. Here again definition of Tech Transfer is important.
3	1.5	Excellent TT candidate.

Priority	X-fer	Comment
		AANWG
3	2	Low frequency technique is more important than bubbler. Bubbler is just before being released. ISU should present its plan for evaluation validation and release.
2	0	Will be useful when A/C are reinspected after modification. At present corrosion inspection not done with UT.
2.5	1	Still problems with large rivet head (causes damage to seal) - Ward offered saul n. Enhanced visual methods may be competitors for speed - already developed?
2	1	Interfacing commercially available scanners would be very useful.
-	2	Drop patent nonsense. This is an engineering application.
3	2	Has promise.
3	2	-
2	-	-
3	2	Needs refinement to eliminate coupling problems over large fasteners. Also needs size/weight of vacuum system reduced.
		FAA
1	1	No clear applications.
-	-	-
2	1	-
2	-	-
2	2	-
2	1	-
3	1.5	-
3	2	Best buy.
		Manufacturer
2.5	1.5	I will talk with Nancy to see how well this adapted to the MAUS (Dwight Wilson). Maybe we can look at this for our textile composites. Right now we are looking into Air Scans for the Test Pro.
		Operators
3	-	Extra application flexibility this offers (e.g. over button-head rivets) makes this technique valuable.
-	-	-
3	2	Need to look at past work - e.g. Martin Marrietta.
		FAA Researchers
3	1	Still need to investigate behavior with large button-head rivets.
3	2	Needs to be applicable to multisite scanner types.
2	2	-
3	?	Having difficulty understanding program for tech transfer from university to airline without benefit of an intermediate instrument company that will maintain, support, train, continuously develop, etc.
-	-	-
2	1	Needs some redesign and more interface with equipment manufacturers.
3	1	Applicable for disbond and corrosion good, but seems quite slow. How fast compared to present methods.
		Other
-	-	-
3	1	Recommend more trials to give direction for best effort field prototype--then do field trials before TT effort.

Priority	X-fer	Comment
		AANWG
3	0	Someone should make a dispassionate assessment of the market for this device before any more money is spent on it.
2	0	No technician to use it good for OEM'S
2	0	X-ray still not usable for many in service problems (i.e., cracks). Manufacturers are avoiding use of X-ray - this work will have to convince them otherwise.
?	?	Not enough discussion as to the benefits/target of this effort. Presented as a solution looking for a problem.
-	-	-
	1	Not sure this will have application with airlines.
	1	-
	-	-
-	-	-
		FAA
1	2	No market. Already commercially available and not selling. X-ray demo - limited market, give it to Boeing/Douglas, anybody else.
-	-	-
-	-	-
1	0	Limited need.
1	2	-
2	1	-
2	0	X-rays are major NDT for commuters, however they tend to be unreliable- this does not appear ready this year.
-	-	-
		Manufacturer
-	-	-
		Operators
2	-	-
-	-	-
-	-	-
		FAA Sponsored Researchers
-	-	?
1	-	Commercial systems available?
?	0	-
2	?	Having difficulty understanding program for tech transfer from university to airline without benefit of an intermediate instrument company that will maintain, support, train, continuously develop, etc.
-	-	-
2	1	-
2	0	Long term for densitometer.
		Other
-	-	-
3	1.5	-

Priority	X-fer	Comment
		AANWG
2	1	I believe the pulse EC is more important than the probe calibrator and a deployment plan should be created for it.
1	0	Good for probe mfr. Operators would be too critical and probes would fail limits.
3	1	Good stuff but still some work to do on user friendly software and POD study.
2	1	Needs demonstration of usefulness of the calibration.
-	2	Do validation in a controlled experiment.
3	2	Needs to be in OEM lab. However ET probes are already too expensive.
2	1	-
-	-	-
1	?	Standardization of probe operating characteristics may be helpful. Abbreviated reliability study should be conducted to determine if POD is actually jeopardized/ or a t what point POD is jeopardized because of low field intensities and if current practice of calibration against a standard is inadequate to detect "unacceptable" probe performance. Higher signal/noise ratios due to higher gain settings to compensate for inefficiency in probes will not typically result in reduced POD 1 S/N), but rather results in increased false calls.
		FAA
2	2	Limited market/give it away - assure tech transfer.
-	-	-
3	2	-
3	2	If this technology can improve the ability to find small cracks, then its development should be accelerated.
1	1	-
2	1	-
2	1	Unclear as to how close they are to FY95 certification, the application is so specific I wonder if it is practical.
3	2	Need by airlines now.
		Manufacturer
3	-	This needs to be coordinated with probe makers and spec. writers. Not sure how to push this issue. Should OEM be responsible for pushing the standards?
		Operators
2	-	Useful, but most users have adjusted to cope with problems. Will need to be inexpensive and easy to do.
-	-	-
3	2	This is like thermal wave--it can be brought to a decision (otherwise its need will remain undefined).
		FAA Sponsored Researchers
3	2	A company could take it immediately and do the value engineering and design for mfg.
1	-	No industry pull? Quantify POD.
3	1	-
3	?	Having difficulty understanding program for tech transfer from university to airline without benefit of an intermediate instrument company that will maintain, support, train, continuously develop, etc.
-	-	-
1	2	Good idea but lacks an industry/airline champion.
2	0	-
		Other
-	-	-
3	1.5	Industry needs ASAP. Good work as usual.

Priority	X-fer	Comment
		AANWG
1	0	There may be a requirement for this technology. A market study should be done to find it.
1	0	Too expensive for benefit. Too small inspection area.
1	0	Still very limited over coverage - for use after some other tech has given indications. Expensive!
1	0	Needs to be sped up to make it practical.
-	-	Delete
2	1	Still looks like it needs more refinement in physical make up for actual use on A/C.
1	0	-
1	0	Interesting research technology.
1	0	Expensive technology with limited portability and application.
		FAA
3	2	-
-	-	-
2	0	-
1	0	Limited need for this instrument.
2	2	-
1	-	-
2	0	Continue-not a scanner - more a specific quantified.
1	0	Expensive, time consuming, labor intensive.
		Manufacturer
2	0	X-Ray simulation (Gray) 3 and 2 This looks like a great engineering tool to me. I would like to see something like this for all NDT methods starting with ET and UT.
		Operators
2	-	Could be used, once simplified and further developed, to verify or characterize specific areas of corrosion (which may be found initially with thermal wave imaging). Cost?
-	-	-
?	-	
		FAA Sponsored Researchers
1	0	Probably too slow. Other methods may be good enough.
3	2	No other systems available.
2	0	-
2	-	Small spot size and slow depth scan speed limits applicability to specific validation applications.
1	-	Seems very limited in application.
1	0	needs hardware updating and more on-aircraft evaluation.
1	1	Small area of scan will limit utility.
		Other
-	-	-
2.5	1	More work on modification of fieldable procedures, support equipment. Not TT obstacles seen.

Priority	X-fer	Comment
		AANWG
1	2	Good solid application on demonstrated need.
3	2	This is a possible money saving item near term.
3	2	DC-10 work has obvious application. DC-9 Took a while to find an application but seems to be on its way now -- success story? (Needed Northwest and Douglas to get it going.)
3	2	Seems like a real opportunity.
-	-	-
3	2	Has promise. current procedure either doesn't work or required too much open-up.
3	2	-
-	-	Should coordinate activities with AANC C-scan imaging program. Does flat bottom hole and EDM truly represent real structure? Does stuffing corrosive product represent sandwiched corrosive product that has never been removed? Hard to believe sealant thickness variations don't affect inspection (if I understand technology correctly).
3	2	-
		FAA
3	2	-
-	-	-
2	1	Need to move low in this technique - anytime you go from a 800 hr inspection to .80 hr there are a lot of pressure on the NDT department at the airline.
2	-	Can the self compensating method be used to find small cracks?
3	2	-
3	2	-
-	-	80 hrs. vs 800 hours justifies going on with validation and <u>certification</u> as an alternate means of compliance. <u>If it works</u>. FY 95 may be aggressive.
3	1	-
		Manufacturer
3	2	My biggest concern of this technology would be the ability of an inspector to perform it without supervision.
		Operators
3	-	Impressive development of this technique to a specific application. Method and software may be very valuable in other similarly inaccessible locations. USCG has areas on our aircraft similar to this and DC10 span cap/strap.
-	-	-
3	2	Further 02 validation effort required for go/no go criteria.
		FAA Sponsored Researchers
2	2	Straightforward acoustic technique that looks easy to implement.
3	2	-
?	1	-
-	-	-
-	-	-
-	-	-
2	0	Looks very susceptible to noise when image processing. I imagine many misses and false calls, event technicians being able to rerun and get different results (i.e., limited repeatability). Do a blind study of several parts with real corrosion flat bottom holes are much easier to call than the gradual changes associated with real corrosion. What is scatter of materials/thicknesses in what (see drawling--How will these two signals be displayed and interpreted?
		Other
-	-	-
3	1.5	Excellent work and potential for TT.

Priority	**X-fer**	**Comment**
		AANWG
1	2	Good report.
2	0	Needs work to make more user friendly.
3	1	Bond inspection is best bet for this. DASH T application has potential.
2	2	Transfer seems to be already taking place. Needs effort to demonstrate real defects are detectable.
-	-	No activity needed - This is a commercial product.
2	1	This technique may produce many false calls. Unless it becomes acceptable to FAA as alternate means it can't be used.
2	1	-
1	0	Technology has not been sufficiently proven to applying for alternate means of compliance. Credibility of sponsors are questioned if they try to promote unproven technologies.
2	0	Must demonstrate reliability/lack of false calls. Needs improved part excitation methods and data presentation/simplified interpretation.
		FAA
-	-	-
-	-	-
-	-	-
-	-	-
2	0	-
2	1	-
-	-	-
3	2	-
		Manufacturer
-	-	We will be trying shearography on our super plastic formed diffusion bonded titanium.
		Operators
2	-	-
-	-	-
-	-	-
		FAA Sponsored Researchers
2	0	Still not obviously a front runner for disbond det.
3	2	Good industry pull.
1	1	-
2	-	Small spot size and slow depth scan speed limits applicability to specific validation applications.
-	-	-
2	1	Interface with LTI is right approach.
3	-	-
		Other
-	-	-
2	?	Too many uncertainties as to resolution, interpretation, reliability of results.

Priority	X-fer	Comment
		AANWG
2	1	The Livermore effort should be coordinated with Thomas work since it has some valuable components If it is to be used on aircraft the application must be better defined
3	2	Appears to have good application to near future needs
2	0	Still not convinced it is better than other enhanced visual techniques for corrosion. May be ok for bonds Still awkward to use - sizes, wt. etc
3	2	Technology seems as mature as it will get without trying to transfer.
-	-	Delete
2	1	This technique may produce many false calls. Unless it becomes acceptable to FAA as alternate means it can't be used.
3	2	-
-	-	-
2.5	1	Expand application to composites. Demonstrate good POD to false call ratio and flaw characterization/quantification.
		FAA
3	2	Now! Now! Now! - Time for Bob to deliver.
-	-	-
1	0	-
2	-	Disbond detection in lap joints.
2	0	-
2	1	-
2	0	Should continue - Could be ready in 95 if they spend time and money. Still they don't have specific application yet.
1	0	Labor intensive-paint clean system unwieldy set up corrosion with P P water.
		Manufacturer
2	0	-
		Operators
3	-	Seams very promising. I'd like to see a version tried on CG HU25. Apply to areas around doublers, antennas etc where corrosion exists
-	-	-
3	2	Lockheed is interested. This hardware is near maturity. We need to bring to a conclusion (good/or bad).
		FAA Sponsored Researchers
2	1	Probably close to being ready for tech transfer. Some concern about acceptance because of need for surface prep.
1	-	Industry competition-Bales.
?	0	-
3	-	Looks like good progress toward fieldability of this technique.
-	-	-
3	1	Almost ready for AANC formal validation.
2	1	-
		Other
-	-	-
3	-	Need trials with field-oriented prototype before initiating TT. Excellent progress, potential.

Priority	Grade	Comment
		AANWG
3	4	Good review. See assessment of Eddy Current Inspection Equipment (First good exposure of results of this unique and excellent program. Some minor problems with draft report. Well presented. Conclusions should be more comprehensive.)
0	4	Results presented at Atlantic City. What has changed?
3	3	This is a key to the whole validation process of new technology. I have some concern about how future POD will be done and whether it will be as valid as the ECIR work.
3	3	With the exception of final report what else will be done? This needs a clear statement of what is the purpose of the study. For real aircraft panels with bending loads, such as the Foster Miller panels some of the cracks can be 10 mils below the surface and run up to 100 mils from the shaft hole. These cracks are not in the panels where the cracks are grown in the flat panels, however more representative of what is in the field.
-	3	Done.
3	4	Good job. However, the inspectors used more time because of knowing that they would be graded. Natural reaction.
3	4	-
2	4	Priority high to establish POD protocol, low as applies to lap splice. Good experiment, good communication throughout program. I would propose POD experiment for Bolt Holes in Steel and aluminum (automated and manual).
?	4	Complete? Good protocol established for further reliability studies. Also good defect library established for assessment of emerging technologies.
		FAA
3	3	Good experimental design. Report needs lots of improvement. Need to start doing data set analysis.
-	-	Presentation was too detailed, didn't really see how it fits into big picture.
3	3	This should be high priority - we need to move into training and certification - using this data. We need to address which equipment can do a better job.
3	4	This activity should be extended to investigate gains that can be made in POD for small cracks using new equipment or procedures
3	4	-
2	4	-
-	-	-
3	3	Need to move toward certification (FAA) Ok inspectors.
		Manufacturer
3	4	This issue is very important. Our ability to correctly state the flaw size that can be found reliably is critical. It affects not only inspection intervals but safety as well. Good job on what you set out to do.
		Operators
3	3.5	On the built-up specimens: since you assume no crack at holes with cracks <60 mils, how do you know that some of the "false calls" aren't coming form cracks <60 mils? I think that the best effort possible was done using current techniques, but I think the "built-up" specimen should be re-baselined in future using technique able to detect <60 mils and then re-do POD curves, which are presently loosely based below 60 mills. Very expensive to do similar studies for other inspections. These results specific to this inspection.
-	-	-
2.5	3.5	Report needs reviewed.
		FAA Sponsored Researchers
3	3	Still some question of interpretation of results.
2	4.5	Lots of good work.
3	4	-
2	2.5	It looks like this topic is being beaten to death. The early results indicate there are no surprises. The more detailed results do not obviously point to ways of improving any aspect of performance.
1	3	I think the importance in this presentation is its use as a template for other investigations-that side was not emphasized enough. Results were not clear, as to their benefit to industry.
3	4	It accomplished what it set out to do; established an important basis of comparison for advanced NDI.
3	4	-
		Other
-	-	-
3	3.5	Answered tough questions. Recommending expansion of trials at more diverse facilities to strengthen data base. What does distribution of POD at specific flaw sizes look like. (see sample - plots like this give good insight.)

Priority	Grade	Comment
		AANWG
3	3	I am uneasy about this project. There has been too much discussion about its goals for me to believe the committee steering it know the direction it should be going. We should better describe what visual insp. can detect. We should better use baseline inspections defined in the AC and develop experiments using the AC, as the framework.
-	-	This program should be presented to another group. More emphasis on training is needed.
3	2	Need to clarify what are objectives, expected output. (Phase I). Concentrate more on corrosion vice cracks. ATA concern is still cracks.
3	2	Needs much more definition. Seems to broad to give significant results. Time frame for completion seems unrealistic
-	-	Stop until a coherent plan is defined and approved.
3	3	This program needs different people, at least from the airlines. Should have more training for visual inspection.
3	2	Not a good presentation.
3	-	Needs much direction - Steve Erickson input most useful. Get airline visual experts involved.
3	2	Requires additional OEM/Operator input to provide direction and define scope.
		FAA
2	1	Guidance panel needs complete restructuring - only human factors issues being assessed - Good efforts on generic protocol being disregarded. Need to do phase I.
-	-	Why are you only now developing a visual program when the visual RPI has been around since 1992?
3	2	Should purchase a commuter hightime aircraft - for visual inspection.
1	2	I think that the R&D effort needs to be thought considering the way that the challenge was originally put to FAA by the Airlines and the manufacturers. Their concern was not with quantifying, in absolute terms, what the POD for visual inspection is, rather, they were asking what could be done to maximize the power of routine visual inspection. There are many things that can be done to achieve this end without trying to quantify the POD for visual inspection. One very simple example might be to establish visual acuity standards for inspectors. It seems to me that these issues can be studied without having to measure precise POD values.
3	1	-
3	4	-
3	2	Need to identify whether we are interested in visual inspections of non-fail safe commuters or not. Somewhere we do need to. Directed NDI inspections (not visual) are not normally a part of smaller commuter airplanes.
3	2	Coast Guard aircraft does not equate with commuter, different utilization, maintenance program. Visual sample buy commuter aircraft (used).
		Manufacturer
3	-	This has typically been the first line of defense. However, for newly certificated airframe, all fatigue critical structure will require a special detailed NDT. With visual inspection we should always keep in mind what we can't see or what can be missed. That will help dictate what we can see reliably.
		Operators
3	3	So much inspection does rely on visual techniques. It's important to characterize the ability to conduct visual inspections. Recommend you look at areas being inspected visually now for corrosion. How effective are present methods? Are there enhancements that can be improved upon? Conditions? I think this is important. Seems on right track initially. Direction, as known to researchers, needs solidifying -- grade 3.
-	-	Continued airworthiness problem - not aging, you've gone to directed inspection of known problems and WFD projected and known. Concentrate on ALT's that can be made visual.
2.5	2.5	Needs more industry involvement per audience comments (structures and maintenance) - coordinate through ATA and Ward Rummell.
		FAA Sponsored Researchers
3	2	I didn't see much happening here.
3	2	Needs to be focussed.
3	2	-
3	?	Very controversial, it appears! Need to get the experts (users!) together to establish priorities.
-	-	-
3	3	Industry input will be essential to success of this program.
2	2	-
		Other
-	-	-
3	3.5	Quantifying reliability will be tough to do.--Also adding "pseudo-flaws" is risky business (characterization is in the eye of the beholder).

Priority	Grade	Comment
		AANWG
3	3	This is good work badly described. The PI is in need of help in getting the technology deployed.
1	3	Who would use this system? FAA? OEM? Contract? Primer on X-ray.
2.5	3	Like to see other methods modeled. Still pushing X-ray for crack detection and I'm not convinced this is the best method for most crack inspections.
2	2	X-ray work is good, however, the use of X-ray for commercial aircraft is limited. Computer codes for simulation of UT systems would be more appropriate. A simple ray tracing routine interfaced to a CAD output would be of greater interest to OEM's and carriers.
-	-	Duplicate -- Don't do low cost densitometer.
1	3	Joe's efforts look pretty good, but I don't see this being utilized by the airlines.
1	3	-
-	-	-
3	4	Providing cost is not prohibitive. Could improve reliability of existing and future inspections as well as act as a good training aid. Computer models should be developed for other NDT processes. UT, MT, and ET in that order.
		FAA
2	3	-
-	-	-
3	4	This could help in smaller/reliability of crack detection which would improve safety - immediate technology transfer from R&D to OEM for X-ray technique.
1	2	This R&D activity has very limited use in solving the aging airplane problem.
1	2	-
2	4	-
-	-	-
-	-	-
		Manufacturers
3	4	-
		Operators
2	3	Need to work with an aircraft X-ray technician on a real problem (perhaps a new inspection or a difficult existing one) and see if the technician can effectively use the software (Unix Workstation availability?) to rapidly improve their inspection results/process. (Use DC9 bulkhead at AANC?).
-	-	-
-	-	-
		FAA Sponsored Researchers
2	4	-
2	3	Good project if technology can be transferred inexpensively.
3	3.5	Field demos are needed.
?	?	Looks like good work, but not obviously generating any results that are not well known empirically in the field.
3	2	Quantification of inspection results is extremely important for data storage over time. Presenter didn't discuss this aspect of computational methods. Good experimental work on quantification of some intuitive relationships.
2	3	-
1	3	Is this to define machine settings to detect the smallest flaw? If you do this once, are you done? (i.e., after you use it once, will there ever be a reason to use it again? Who in industry would ever use it on a regular basis?) Would money be better spent doing trial and error in the lab?
		Other
-	-	-
2	.5	Need much more refinement and validation experiments to get confirmation of predictive power of model (and utility. Concept is good-hope it is successful.

Priority	Grade	Comment
		AANWG
1	1	Not a particularly exciting technology although some of the work on corrosion which supports it is good and should be expanded.
1	1	Needs redirection. Cannot differentiate between sealant, corrosion, mfr. pillowing.
2.5	1	Still work to be done. Already supporting this - current level of support is appropriate. Example of successful joint (FAA/TC/NRC) venture.
1	1	Without quantification of the images, this technique is of little or no use. It is not clear from the presentation quantification is possible.
-	4	Rigid plan required before proceeding -- needs a user champion - D-site organization minimum participation.
1	3	Separating out false call will be very time consuming.
1	1	-
2	2	Variability of manufactured panels (new planes) May have much inherent distortion. Natural variation of structure should be investigated.
1	2	Shows improved detection capability over visual inspection - however visual inspection has not proven inadequate. Still requires other technology to characterize flaws.
		FAA
0	1	Waste of time and effort.
-	-	-
2	3	Long way to go for aircraft use.
-	-	-
3	2	-
2	4	-
1	4	Seems to be well defined now. Industry needs to pick up on it or it needs to fall by the wayside. Without a customer, improved equipment with no market is a waste.
3	2	Unwieldy, can't imagine dept. under c check having inspector.
		Manufacturer
2	-	D-Sight sees a lot--maybe to much. Creates a lot of false calls and additional work. Good technology but probably needs to be focused towards a specific task like impact damage of composites, or special applications to find specific thins in specific areas.
		Operators
3	3.5	Seems very promising. Should be "competed" against thermal wave imaging, eddy current and ultrasound techniques for finding corrosion in terms of criteria such as flexibility to other inspection applications, false calls due sealant, etc (which has also cause pillowing), cost.
-	-	Is D-sight intended as a screening technique or as a final determination. If so, what is its POD/POFC as compared to POD aided visual?
2	2.5	Still lacks quantitative element. What about ripple in new airplanes - how to interpret?
		FAA Sponsored Researchers
2	3	Progress toward an operational device. Is there a quantitative way to interpret images or is it mainly objective?
3	4	A low-cost version would be a great addition to the wide area inspection tool arena.
-	-	-
?	?	Looks very encouraging...are the airlines buying it? (It seems ready for the market...not clear further research is needed.
2	3	As presenter explained, lap splice inspections are becoming obsolete. Attempt to find more applications and adapt technology for these applications. Excellent review of background of corrosion development and also potential time savings.
3	3	Need to work out a "baseline subtraction" capability since D-sight produces indications even in a brand new aircraft-(rivet assembly to tolerances produce acceptable surface irregularities in production).
3	3	Try to quantify POD of cracks.
		Other
-	-	-
3	4	Excellent prospects. Convincing progress.

Priority	Grade	Comment
		AANWG
-	-	Not given the show more should be explained before it is dreamed up by someone else.
1	1	Did not review.
3	4	Flashlight diffuser good stuff - available now.
-	-	-
-	-	Rigid plan required before proceeding.
2	3	A couple years ago at the ATA NDT forum I saw light being transferred from a high intensity light source by a fiber cable. This produced a bright uniform light beam without heat. This method needs to be evaluated.
3	3	-
3	4	Simplicity is best.
3	2	-
		FAA
-	-	-
-	-	-
-	-	-
-	-	-
3	-	-
2	4	-
-	-	-
-	-	Mag Light- Difusser - Good idea, should be UL approved to enter fuel tanks or areas around sext.
		Manufacturer
2	-	Finding and developing and learning how to use tools that enhance visual inspection is a worthwhile task. But the tools need to solve more problems than they create.
		Operators
-	-	-
-	-	-
-	-	-
		FAA Sponsored Researchers
3	?	Not clear to me what tools are in this category.
-	-	-
-	-	-
-	-	-
-	-	-
3	4	Potential for low cost visual enhancements.
3	4	-
		Other
-	-	-
3	4	Good plan. Task definition should have comments from selected outsiders before implementation to assure optimum plan.

Priority	Grade	X-fer	Comment
			AANWG
3	4	1	Good technology. Well applied. May be useful in characterizing corrosion in rivet garrels.
2	3	-	Could do some work to apply to more complex structures such as heavier A/C structure.
2	2	0	No applications selected yet - progress has be slow. Still a lab technique - needs to be packaged for field use.
1	2	0	Not a clear advantage over conventional UT techniques which would be required for justifying increased complexity and loss of sensitivity. Needs good comparison to conventional UT. No significant progress in last year.
0	0	cancel	A solution of questionable value, looking for a problem. If successful, no application concept is evident.
2	4	1	-
2	4	1	-
2	3	0	Potential application for composite - could be useful in this area.
1	2	0	Doesn't show advantage over ET for surface flaw detection. Expanded application may increase priority/usefulness.
			FAA
2	2	2	Put up or quit playing.
-	-	-	-
3	3	0	Good possibility - need to be used at the validation center.
1	2	0	This appears to have limited use for aging airplanes. Does this have any potential to find smaller cracks than eddy current? I would like to see a feasibility study on how this would benefit the aging aircraft program.
1	2	1	-
1	3	0	-
1	2.5	0	Still requires considerable operator interpretation. Probably still impractical for commercial use.
3	3	.5	Need to scan. Easy to use. Expensive? Composite repairs.
			Manufacturer
2.5	4	.5	Would be interested in getting feasibility scan of diffusion bonded super plastic formed titanium (Dwight Wilson). Maybe some dollars available this year.
			Operators
2	2.5	-	Presently seems extremely labor intensive, time consuming; however it appears to be the only "reliable" method for detecting/measuring small cracks. I cannot see how an inspector could use if had t measure 15-20 pts per rivet. Automate? Robotics? Expense?
-	-	-	-
-	-	-	-
			FAA Sponsored Researchers
3	4	0	Could be a good alternative to fluid coupled UT.
2	3	0	Detect cracks in fuselage panel. Fiber optic laser systems. Suggested get into AANC.
2	3	0	Applications have to be more focused.
2	4	2	Has interesting possibilities for automated deployment.
1	3	-	If it is as broadly applicable as presenter claims, this should be further developed. Very clever engineering design, although it looks as if developers are already doing this.
1	2	0	-
2	3	0	How will this work in a shop environment? e.g. is it susceptible to dirt, etc.? Some tech already transferable, but some is long term.
			Other
-	-	-	-
3	4	1	Get experience base with upcoming compact prototype first.

Priority	Grade	X-fer	Comment
			AANWG
3	4	2	Good work well presented.
3	4	2	M/D spar wip.
3	4	1.5	DC9, DC10 applications already underway. More applications will likely surface from this. Two step transfer makes sense - i.e. crack detection and than characterization.
3	4	2	Good application. Helps the airlines feel that they are getting something out of their participation.
2	2	2	More validation - don't develop another computer data collection system.
3	4	1	-
3	4	1	-
2	3	0	What is the above and beyond cost for this system as opposed standard UT system?
3	3	2	If AMOC approved. Further development in flaw characterization only useful if OEM's define "flyable" crack limits.
			FAA
2	3	2	-
-	-	-	-
2	3	1	Need to stay with this direction.
3	3	2	How small a crack can this technique resolve? This appears to have application in detecting cracks in the second fuselage skin layer. Would it have an advantage over eddy current methods?
3	2	2	-
3	4	2	-
3	3	1	Practical second layer inspection. Need commercial applications and manufacturer sponsor to get method approved.
3	3	1	Need penetrating verification use other places also.
			Manufacturers
3	4	2	-
			Operators
3	4	-	Practical, effective application of technology to a difficult problem.
-	-	-	-
3	4	2	Douglas wants this bad for DC10--is impatient that it's not there.
			FAA Sponsored Researchers
2	3	1	Effect of crack orientation is significant and may cause operational difficulties. It was not fully addressed.
3	4	2	Sonix. Being applied to actual problems. Second layer cracks.
3	4	2	-
2	4	2	Sensitivity to crack orientation may make it difficult to employ in some of the tight areas for which it is designed.
3	3	-	It is good to see researcher responding to industry needs, but be careful not to custom-design a technique for only one application. This is not an effective way of transferring technology.
2	4	1	Good compliment to other UT projects.
2	3	1	-
			Other
-	-	-	-
3	4	1.5	Good work--good results--a winner.

Priority	Grade	X-fer	Comment
			AANWG
3	3	1	The work needs a better definition of the inspection procedure, and a protagonist in an airline. Perhaps a tech transfer plan would find such a person.
3	4	2	Shows promise for con det.
2	2	0	Packaging for field use still needs work. May not be any better for corrosion detection than older enhanced visual methods - that leaves disbonds (composites)
3	2	1.5	Seems as mature as it is going to get, should be transferred. Much of the work shown has nothing to do with the aging aircraft program. Steel sample is not at all representative of Al and is much thicker than typical aircraft parts in fuselage (~1"). New aging aircraft results are sparse.
1	0	done	Give software to users. No additional work is indicated. Commercial available. Nothing new since last year, did we fund?
2	4	1	-
2	4	1	-
3	4	1.5	Work should continue. Presently we have both NASA and Wayne State software for evaluation.
2.5	3	1	Consolidate (see previous comments).
			FAA
2	3	2	-
-	-	-	-
2	2	0	Still a lot of questions, as to how well it works.
3	-	-	Can this method detect weak bonds?
2	2	2	-
2	3	1	-
1	2	0	Seems to be good large area corrosion identified but I don't see any plan to get practical application.
2	2	0	Can't say for sure what reading indicates large percent false calls.
			Manufacturer
2	-	0	-
			Operators
3	4	-	Efforts to improve portability, flexibility and reliability are on track. This technique seems to offer excellent potential for relatively quick characterization of corrosion, disbonds and even the existence of working/loose fasteners. I also like mapping ability. I'd really like to see if this technology is capable of detecting moisture in honeycomb composite structures, which is common problem on C6 helicopters (J. Moukawsher).
-	-	-	-
2.5	3.5	2	It looks like LLNL is ahead in interpretation and WSU in hardware. The best elements of the lives of this and Dual Band Infrared Imaging should be combined!
			FAA Sponsored Researchers
3	4	0	Good progress. Need to determine acceptability of users who have to paint the surface. The rig is still somewhat cumbersome to use in a hangar environment.
3	4	2	-
3	4	0	-
3	4	1	Terrific progress. The overlap and distinction between these two projects should be clarified (Dual Band Infrared Imaging). Techniques are a little different, results look very similar.
3	4	not ready	Excellent presentation. Technology appears promising at early stage - perfect opportunity for FAA to help advance a technology to the commercialization stage.
3	3	1	-
2	3	0	Transfer won't occur until you can differentiate disbond from corrosion from thinning from....
			Other
-	-	-	-
3	4	not sure	Have we got all the evaluation/validation answers yet? e.g., some unexplained indications from lap splice inspection. Get as much field experience as possible before attempting Tech. Transfer.

Priority	Grade	X-fer	Comment
			AANWG
3	3	1	Ill should develop a catalogue of corrosion signatures for use by inspectors. Current studies need better organization but are on a sound theoretical basis.
2	4	2	Will be good if it will give indication of corr. as opposed to sealant etc. Also good for composites.
2	2	0	Duplication of Bob Thomas work? Batkes has prototype. Thermal Inertia work has merit.
1	2	0	Much of the effort does not require dual band, plus dual band significantly increases cost. Needs to demonstrate that "clutter" is a real problem for aircraft measurements/inspections. Analysis techniques considerable different than WSU, requires very quick measurements of temperature.
2.5	3	2	Dual energy worth added assessment. Need a well defined plan. Bring to closure.
2	4	1	-
2	4	1	-
1	2	?	With NASA and Wayne State what is the benefit of adding another IR effort?
2.5	3	1	Consolidate (see previous comments).
			FAA
1	2	2	-
-	-	-	-
1	2	0	-
1	-	0	Can this method detect weak bonds? This technology does not look like it's close to a practical tool yet.
1	2	0	-
2	3	1	-
-	-	-	Thermal Inertia shows promise to show corrosion in deep layers. Could be good method to show corrosion on Aero Commander 112 Aircraft.
2	2	0	-
			Manufacturer
2	-	0	-
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
2.5	3.5	2	It looks like LLNL is ahead in interpretation and WSU in hardware. The best elements of the lives of this and Dual Band Infrared Imaging should be combined!
3	4	0	High priced equipment. Concept needs to be implemented with much less expensive equipment. Maybe a cost-benefit analysis will show that it is worth the high price.
			FAA Sponsored Researchers
2	3	2	What is difference/advantages re. Wayne State method?
-	-	-	-
3	4	1	Terrific progress. The overlap and distinction between these two projects should be clarified (Thermal Wave Imaging). Techniques are a little different, results look very similar.
-	-	-	-
1	2	0	-
2	4	1	Good--coordinate w/Wayne State? Any way to make it cheaper?
-	-	-	-
			Other
3	3.5	not sure	Have we got all the evaluation/validation answers yet? e.g., some unexplained indications from lap splice inspection. Get as much field experience as possible before attempting Tech. Transfer.

Priority	Grade	X-fer	Comment
			AANWG
2	3	1	We should gather more empirical data on bond character using LD Freq. UT
2	4	2	Will be useful for modified joints. Also possibilities for composites.
2	3	0	Lap joint application demonstrated may have other faster methods evolving. More applications and improvements in design needed (from seal etc. layer bridge).
3	4	2	Excellent results scans need to be speed up and insure the quality of the ( ) does not deteriorate.
3	4	2	Detected 15-20% net loss. Put in the field.
3	4	1	Has more promise for actual use on A/C
3	4	1	-
3	4	1	Good work for potential future problems. Having "B" scan capability could enhance understanding of the structure.
3	3	2	-
			FAA
2	2	2	-
-	-	-	-
2	3	1	Needs additional development - on aircraft.
3	4	2	Can this technique detect weak adhesive bonds? This technology appears t be close to a practical instrument, particularly in combination with the dripless bubbler.
2	2	2	-
2	3	1	-
-	-	-	-
3	3	1	-
			Manufacturer
2.5	4	1	Looks like some good work done here.
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
2.5	3.5	0	It seems like "dripless squirter" head is developed, this work should end. It also synergizes with Komsky work.
			FAA Sponsored Researchers
3	4	1	Probably can be moved into commercial arena with a little more experimentation with surface conditions.
3	4	2	-
3	4	2	-
3	4	?	Good progress. Commercialization will have to address lifetime of seals in field use.
-	-	-	-
2	3	1	Mechanical assistance is important aspect; didn't see anything new in UT; how about mating this with Carnegie Mellon robot.
1	2	0	I am not convinced that, within the calibration variations in ultrasonic equipment and other noise, that you can reliably tell disbonds from corrosion.
			Other
-	-	-	-
3	4	1	Looks good. Do we have enough evaluation for range of possible inspection scenarios? Suggest more trials to prepare for TT (include equipment improvement).

Priority	Grade	X-fer	Comment
			AANWG
?	-	0	?
2	1	0	Connection to shearography makes it questionable use for operator.
3	4	1	Enhances Shearography effort - will be key in acceptance of LTI's system - not sure ESPI is necessary if shearography works.
2	3	1.5	Needs more work to demonstrate that same results are possible on real samples with disbonds which do not have regular shapes and where the rivets are present - overall this is very good work.
2	3	2	Get to field immediately. Implement close out in 1994.
2	4	0	-
2	4	0	-
2	3	0	Work is at least directed at improving the technology which is required prior to implementation.
1	4	?	Good work on improving S/N ratios. Tech transfer seems complete?
			FAA
2	2	2	-
-	-	-	-
1	0	0	Long way to go for aircraft use.
-	-	-	-
2	2	0	-
2	4	1	-
-	-	-	-
1	1	0	Too far in future for live aircraft use.
			Manufacturer
-	-	-	-
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
2	2.5	0	Work needs to be performed on excitation stimulus.
			FAA Sponsored Researchers
2	4	1	Good technical work. It appears to be early in development and tech transfer is not yet a consideration.
3	4	2	Good prospect for tech transfer.
2	3	0	Need to show complex specimens interpretation.
2	4	?	Excellent work, but think very far from being usable in the field.
2	4	already done	Excellent evidence of tech transfer.
1	2	0	-
3	4	1	How do you tell disbond from corrosion from excess sealant from ripple from 'tweaking' of beam intensity sounds like black magic--can it be quantified/standardized? What are the fringe patterns from regular substructure? Will minor disbonds/corrosion be overwhelmed by these?
			Other
-	-	-	-
2	4	not sure .5	Good work. Need more experience with technique.

Priority	Grade	X-fer	Comment
			AANWG
3	3	2	Good work well presented.
1	1	0	Says it will be user friendly. Not user friendly poor candidate for operator use. Needs further development.
3	4	1	Dash 7 application - no progress being made here. Based on Steve La Rivier's comments - still a ways to go. COBRA should help here.
2	2	0	Not clear what the objective of the project is. Seems at time to deal with how to calculate displacements in real fuselage which is a major effort. Should be focused on calculation of optic response based on input of surface displacement - looks at cracks instead of disbonds.
1	3	-	Advise FAA not to approve based on data present - (This will be test case).
2	4	0	-
2	4	0	-
2	3	0	Boeing may be interested in being a Beta Test.
2	3	0	See previous comment.
			FAA
2	3	2	-
-	-	-	-
1	1	0	Long way to go for aircraft use.
-	-	-	-
3	2	0	-
2	4	1	-
-	-	-	-
			Manufacturer
-	-	-	Although I am very ignorant in the technologies of ESPI and shearography, I think modeling is going to be a major too in the future for engineers assigned to the task of developing inspection.
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
0	0	0	No corrosion research, disbonds only.
-	-	-	-
3	3.5	0	This is not ready but offers real opportunity to tie structures and NDT together.
			FAA Sponsored Researchers
2	3	.5	It's not obvious that enough real-world conditions can be modeled.
3	4	2	-
2	4	0	-
2	?	?	Do we really have to do this from scratch? There are (I think) companies that could productize the concept in a standard interface.
2	4	-	Good example of how industry can deal with prohibitively high capital costs. Also, a good example of FAA interaction w/industry.
2	3	1	Useful work which should be meshed with NU and LTI shearography work.
3	3	0	Can this be used to interpret patterns or do you have to guess and compare trial and error? Couldn't judge fidelity of process from presentation.
			Other
-	-	-	-
2	3	1	Need for capability is tied to uncertain fortunes for shearography.

Priority	Grade	X-fer	Comment
			AANWG
3	-	1	Extremely useful work. Great potential coupled with robotics. Needs deployment plan.
1	1	0	Already have disbond detectors. This has thru trans for skin.
3	4	1.5	Seems like this is ready to go. Need applications to make it fly.
2	2	1	Needs better comparison with conventional techniques.
3	4	2	Get to field quickly - don't need an endless research task.
2	4	0	Would be very time consuming unless used only for spot inspection.
2	4	0	-
2	3	0	-
2	3	2	Advantages - low cost - relatively simple. Disadvantages - localized inspection method - No defined advantage over existing disbond methods.
			FAA
2	3	2	-
-	-	-	-
-	-	-	-
-	-	-	This method does not appear to be quantitative.
-	-	-	-
2	4	1	-
-	-	-	-
-	-	-	-
			Manufacturer
3	4	.5	This looks pretty promising. Would this work on diffusion bonds for poor bond/good bond maybe even to determine bond strength.
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
1	1	0	Technique is structure dependent, small area, and competes too much with other technologies.
			FAA Sponsored Researchers
1	-	-	Can't evaluate. I expect lots of problems with signal interpretation in real applications.
2	3	1.5	Too variable for field application.
2	4	2	Interpretation of sequel difficult.
2	4	?	Hard to get it working in the field?
-	-	-	-
1	2	0	Much noise and interpretation difficulties to contend with.
1	3	0	Would transmission be dependent on bondline thickness? How big a variation will cause problems and look like a disbond. How much signal processing of data is needed?
			Other
-	-	-	-
2	3.5	?	I am unsure about how much performance validation data from field tests is available (looks too untested).

Priority	Grade	X-fer	Comment
			AANWG
3	4	2	This looks like it is immediately transferable. Someone should find an industrial partner for this work.
-	-	-	-
-	-	-	-
-	-	-	Work not presented, but demonstrated - seems to have high potential - needs to be implemented on standard probes.
3	[illegible]	1	Not presented - Great work.
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
			FAA
2	2	2	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
3	4	1	-
-	-	-	-
			Manufacturer
2	-	0	The current corrosion control plans rely heavily on visual inspection. I think the airlines will tell you that current systems in place to find and treat corroded areas are working if there is a dedicated effort made. That said, having more discriminating tools, available and already developed, is a real plus for me if I were to have to move quickly from a visual approach to a dedicated NDT technique.
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
-	-	-	-
-	-	-	-
			FAA Sponsored Researchers
3	4	.5	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
			Other
-	-	-	-
3	4	1.5	Good work--looks ready for tough field trials.

Priority	Grade	X-fer	Comment
			AANWG
1	2	0	Needs market survey.
-	-	-	-
-	-	-	-
-	-	-	-
3	-	-	Not presented - straight forward engineering.
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
			FAA
2	3	2	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
2	3	1	-
-	-	-	-
-	-	-	-
			Manufacturer
2	-	0	The current corrosion control plans rely heavily on visual inspection. I think the airlines will tell you that current systems in place to find and treat corroded areas are working if there is a dedicated effort made. That said, having more discriminating tools, available and already developed, is a real plus for me if I were to have to move quickly from a visual approach to a dedicated NDT technique.
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
-	-	-	-
			FAA Sponsored Researchers
2	4	1	Not obviously the most cost-effective way to go. Alternative techniques may be preferable (IR or UT) (maybe even EC).
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
-	-	-	-
			Other
-	-	-	-
2	3.5	?	Not sure where we are in this effort. How much/little do we know from field testing?

Priority	Grade	X-fer	Comment
			AANWG
3	3	-	See earlier robotics - (Many of the automated detection techniques appear to be candidates for the CMU crawler These should be evaluated in terms of their effectiveness when combined with robotic locomotion.) CMU economic analysis? Why not Sandia, NWU? Work is progressing satisfactorily. Are we sure this is the best configuration for effective tech transfer?
3	4	0	Priority based on continued investigation of feasibility. Good work going on.
2	2	0	Call me a dinosaur but I still have trouble seeing this used in the near future. Probably needs to be remote (radio controlled)
1	2	0	Has an economic study been done to show the has any possibility of being economically feasible? This type of robotic system is typical considered only when cost of human performing task is prohibitive. i.e. space repairs and inspections.
0	-	-	Not reviewed - NIST has R&D Robotics program. Don't reinvent.
2	3	0	Looks very expensive to purchase and maintain.
3	4	1	Lot of potential. Would like to see a tetherless system that could be utilized in a non-hangar environment.
1	3	0	Has the FAA looked at the robotic "tank" designed for painting/strapping airplanes (Seattle based company)? Money could be used to reduce their design. Their design appeared very robust. If unaware of this company, give me a call (Steve LaRiviere). Also has there been an industry survey demonstrating a desire to have one of these for in-service inspection. Why aren't they using off the shelf sensors/software?
2	3	0	May prove beneficial in large area "C" scan imaging and also airframe real time X-ray inspection.
			FAA
1	2	2	No reasonable application.
-	-	-	Good industry interaction, demand appears to be strong.
3	4	1	If this technique was used, it would standardize the inspection which would give a 100 % inspection from operator to operators - this unit need high priority.
3	4	0	This looks like excellent technology that will be needed for future large area inspections. I believe there will be a high priority for it in the future.
1	-	0	-
2	3	1	-
3	4	0	Needs more development but has bright future.
3	3	0	Need work, need to identify skin corrosion as well as rivet cracks. Work around patches, repairs etc. Need to inspect in fuel tanks, vertical fins, use robots for inaccessible or non desirable areas.
			Manufacturer
1	2	0	A big portion of the time we are asked to look for specific flaws in specific directions over small surface areas. Our aging aircraft fleet doesn't lend itself well to this technology because of the lack of uniformity in hole alignment, fastener types, sizes, etc. By the time that is accounted for to the point where you can leave this system and walk away, I think you will find the detectable flaw size has grown. This looks more promising for automated detail inspection of parts prior to assembly. We currently use mag. and pen. for most of this. I don't know if it's true but the system appears slow.
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
2	3.5	0	There is a lot more work which needs to occur.
			FAA Sponsored Researchers
3	4	0	Good progress. Applicable to deployment of many of the new sensors under development in NAARP.
2	3	0	Good idea to have US Air on team.
2	2	0	I suggest that they should aim for minimum system first. Not all bell and whistles.
3	4	-	Fantastic work!
2	2	not ready	This technology is still in a premature stage. Research needs to continue to find a valuable application to the industry. The technology needs a demand-pull application.
2	3	1	-
-	-	-	-
			Other
-	-	-	-
2	3	0	Good R&D of robotics and data processing but too complex to be TT to the NDI real world. Cost-effectiveness and inspector replacability not there as I see it.

Priority	Grade	X-fer	Comment
			AANWG
0	0	0	We hear this same presentation every year despite assertions that it is not the application for neural networks. There is little evidence of progress since last year. There seems to be a weak bond between the technology and the need in both applications.
3	4	2	Appears to have good near time applications.
2	3	1	I am surprised to see the improvement achieved using N.N. an already automated system. Adding neural nets to it -- its time to get on to other applications (fan disk).
3	4	1.5	Too much discussion of neural networks in presentation - results look very promising, particularly for the fan disk inspections - implementing in a system which can develop a higher confidence should be considered.
0	0	cancel	A very, very, very narrow theoretical solution looking for a problem. System is impractical due to signal variance in EC. A very bad application concept. May have some value in visual or X-ray images. Commercial units for small parts are available.
2	4	1	Looks promising.
3	4	2	See the need for additional beta testing. Data presented is dated due to changes in wheel testing equipment. Lot of potential for fan disc testing.
2	2	.5	FY 95 for wheel application. Long term for most other applications. Interesting tool but many commercial systems are available.
2	2	2	No deliverables to date? Use it, prove it or get rid of it.
			FAA
1	2	2	Throw out the neural nets portion, only thing worthwhile here is the implementation of reasonable technical knowledge in area of Eddy Currents. Time to implement.
-	-	-	Good industry interaction, demand appears to be strong.
1	2	1	Wheel inspection today does detect cracks. If were increasing time decreasing man-hour it is a concern but not the top priority which is safety.
3	3	0	I would like to see this applied to fuselage skin lap joint eddy current inspection to see if this improves on POD for small cracks.
3	3	2	-
3	4	2	-
-	-	-	-
0	0	0	Worthless.
			Manufacturer
1	2	2	I think if we are serious about finding small flaws reliably, we are going to have to start interfacing some technology with what we currently use or some of the emerging systems. Image processing seems a lot less sensitive to system changes than this--and no training is required.
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
2	3.5	0	Additional work has been performed since last year but there is no quantum step. Training set (data) remains an issue.
			FAA Sponsored Researchers
3	4	.5	Needs a lot more samples in training sets. Neural nets are recognized as very effective in pattern recognition of interpretation.
2	3	2	-
2	4	1	-
1	3	-	The model based work should be pushed to its limits before resort is made to an ignorance based method. This approach (NN) to eddy current is already well developed in the nuclear power industry.
-	-	-	-
3	4	0	Neural nets development is long term.
-	-	-	-
			Other
-	-	-	-
3	2.5	.5	Excellent potential. Get a lot of real NDI data experience and optimize process that minimizes relearning every time the EC procedure/flaw combinations change.

Priority	Grade	X-fer	Comment
			AANWG
1	3	1	We use existing tools from image processors to configure a unique system for aircraft applications. The system needs a real inspection system. The majority of xray is done using film systems. How big is the market? What is the potential for this technology?
3	4	2	Good work. There is a need for a low cost image manipulation system. Should work toward similar effort in film type system.
2	3	1	A lot of demo emphasis centered around crack detection for which X-ray is your last choice in terms of reliability - need to show/emphasize how real-time X-ray might improve POD compared to film.
0	0	-	There exist a variety of commercially available systems on the market which already do this procedures. The techniques are so simple, with the exception of software development (which is commercially available) it is a one day project. Thermal systems have been doing this for years.
2	2	2	Put unit in field as planned. Make software available (public domain). This is straight forward engineering. Not R&D. Commercial units are available - is this really low cost?
3	4	1	A low cost, user friendly processor is needed to make real time X-ray useful.
3	4	2	Would like to see the results of on site beta testing.
1	2	0	It appears this type of image enhancement technique have been around (off the shelf). Am I correct?
2	2	1	Real time systems still somewhat cost prohibitive because of limited application and cost of part handling systems. Redirect efforts develop low cost system for digitization and image processing of film based X-ray.
			FAA
0	2	2	16 Bit data on 512 monitor for crack detection is absolute nonsense.
-	-	-	Good industry interaction, demand appears to be strong.
1	2	0	Same as above burner can inspection (real time X-ray) is detecting defects - maybe use in other inspection.
1	-	0	X-ray inspection does not lend itself to large area inspection for small cracks.
3	3	-	-
3	4	2	-
3	2.5	0	Need to take real airplane parts - suggest looking at spars from Tech Center Owned fairchild Metro used in previous crashworthiness studies.
2	3	1	How may real time X-ray in use?
			Manufacturer
1	3	2	-
			Operators
-	-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-	-
2	3.5	?	May be a good candidate. Technology is mature. What is extent of critical need? What are commercial competitive options?
			FAA Sponsored Researchers
3	4	1.5	Needs develop calibration procedure for real applications.
2	3	2	Commercially available systems?
2	3	1	-
2	3	-	This technology is well known in other fields.
-	-	-	-
2	3	1	-
-	-	-	-
			Other
-	-	-	-
2	3	?	Some of the technology is already available and in commercial use.

Priority	Grade	Comment
		AANWG
3	4	-
3	4	Good talk.
3	4	This remains a big challenge - glad to see we recognize the need to analyze the process and find ways to improve it. Excellent talk - case study approach makes sense.
3	-	important, but I am not qualified to judge merit of this work. It is one point of view, however, I am not knowledgeable or to the existence of equally viable approaches. Most of this seems like common sense; yet covers issues which are not typically considered by researchers which are developing new techniques.
0	-	Presentation A, Applicable F. An interesting after dinner speaker. He says he will return. Why?
-	-	A vision as to cost effective management - interesting subject.
3	4	Excellent presentation.
2	-	Some aviation success 1) low frequency eddy current, 2) automated bolt hole, 3) shielded pencil probe, 4) videoprobe, 5) sliding probe. Failures? - 1) acoustic emission.
3	-	-
		FAA
3	4	Excellent lunch time presentation - no though t of what we are doing. Priority 0 and grade 1 on project.
-	-	This was same presentation he gave at Tech Center, do we have a task or he is still doing a sales pitch?
-	-	Good information.
-	-	-
2	3	-
3	3	-
?	?	Didn't understand purpose or product. Why?
3	4	Aron great see inside industry.
		Manufacturer
3	4	Thank you for including methods and applications because this is most of what we do as NDE engineers. I needed this breath of fresh air prior to taking my flight home.
		Operators
-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	A sermon for the choir? Best comment fed gov't should not but tech transfer. Market should.
3	NA	-
		FAA Sponsored Researchers
3	4	Good professional tutorial. We need to understand the process in the airline industry.
3	4	-
3	4	Please disseminate this information to us -- this is outside our field but we need USIS information.
3	4	The technical research community should have more frequent and extensive contact with this work...we need to learn these things sooner not later.
3	2.5	Very interesting presentation. Needs to develop a more specific appreciation to airline maintenance.
2	3	Presentation indicated that current effort is at an academic lecture level; needs to incorporate aviation industry in general, and NDI in particular.
-	-	-
		Other
-	-	-
3	4	Important to do to gain from applying lessons learned. Should provide important guidelines for optimizing TT efforts.

Priority	Grade	Comment
		AANWG
3	4	-
3	4	Still very mysterious as to future results.
3	3	Need to be sure the breakdown of tasks (60 tasks) will include NDT - some AMT's don't do any at some facilities.
-	-	Object of this project is not clear.
2	2	Inefficient data to grade. Objectives, process, prioritization and accountability are unclear. This is not just NDT. We need a broader understanding. This is political. Is there a conflict of interest?
-	-	I agree that changes must be made in qualifying ADP mechanics.
3	4	-
-	-	This was the first time this committee saw this presentation. I had a difficult time understanding the "situation/target/proposal."
3	-	-
		FAA
3	4	Another lunch time talk - no content. Priority 0 and grade 1 on project.
-	-	-
-	-	-
2	-	-
-	-	-
2	3	-
-	-	-
3	4	Complete overhaul of 65 5 197 required.
		Manufacturer
2	2	I think job task analysis is probably an important task but I unfortunately was not able to track the goals, the priorities, where your at and where your going.
		Operators
-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	This is a continual airworthiness problem, not aging persc. Where are we going with this?
2	2	From the presentation, it's not apparent how useful/effective this is going to be. Implementation of results is key.
		FAA Sponsored Researchers
3	?	Unable to judge.
-	-	-
3	4	-
?	?	I found this discussion abstract and diffuse; maybe I need more background of it to make sense.
3	3	Interesting ideas were presented. Very well-thought out ideas were presented in a somewhat scattered form. Good work!!
2	2	Again, better ties to maintenance environment are needed.
-	-	-
		Other
-	-	-
3	4	Important

Priority	Grade	Comment
		AANWG
3	4	-
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3	4	-
-	-	This was the first time this committee saw this presentation. I had a difficult time understanding the "situation/target/proposal."
3	-	-
		FAA
3	4	Another lunch time talk - no content. Priority 0 and grade 1 on project.
-	-	-
-	-	-
2	-	-
-	-	-
2	3	-
-	-	-
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		FAA Sponsored Researchers
3	?	Unable to judge.
-	-	-
3	4	-
?	?	I found this discussion abstract and diffuse; maybe I need more background of it to make sense.
3	3	Interesting ideas were presented. Very well-thought out ideas were presented in a somewhat scattered form. Good work!!
2	2	Again, better ties to maintenance environment are needed.
-	-	-
		Other
-	-	-
3	4	Important

Priority	Grade	Comment
AANWG		
3	4	Brasche description of course very good. Good basis laid. Slides good-well managed presentation. Should be used as basis for other FAA-wide training.
3	4	Some question remains about effectiveness of inspector without knowledge of NDT.
-	-	Didn't see.
-	-	Suggestion - Add topic of new emerging technologies.
3	2	Routine presentation. Accountability is not evident in the presentation.
-	-	Right on target. I see acceptance from the local inspectors.
3	4	-
3	4	When technical "how to" data is collected we (Boeing) may be interested in participating. (We may even have some engineers who would like, and could benefit from, being guest instructors). I would like to know the applicability for use to train our source QC people.
3	-	-
FAA		
3	4	-
-	-	-
-	-	-
-	-	-
-	-	-
3	4	-
-	-	-
-	-	-
Manufacturer		
3	4	Absolutely agree with the focus of training toward FAA personnel. We sense from our customers that the FAA can be fairly heavy handed in the interpretation of inspection instructions. I think you are very clear on what you want to do and how you're going to get there.
Operators		
-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	-
-	-	-
FAA Sponsored Researchers		
3	4	Looks good. FAA needs to know how to do its job so program is valuable.
-	-	-
-	-	-
2	4	Good work.
-	-	-
-	-	-
-	-	-
Other		
-	-	-
3	4	Important

Priority	Grade	Comment
AANWG		
2	3	Suggest market study for this effort. Very powerful technique.
3	4	X-ray training is an important area for development. Sooner the better.
-	-	Didn't see.
3	4	Should be excellent tool for training.
-	-	-
-	-	Looks good.
3	4	-
3	3	This also would be beneficial in factory training. Again, technical input is something we would like to participate on. Training materials is the most useful deliverable of the NDI program. Also don't neglect hands on training.
3	4	Add software for other NDT methods.
FAA		
2	3	How any different form Joe's earlier presentation.
-	-	Looks good, is there any demand for this?
3	4	Needs to get to both the OEM and industry - very important in addressing safety! (A very good training aid).
-	-	-
-	-	-
3	4	-
-	-	-
-	-	-
Manufacturers		
3	4	As an engineer, I need these types of tools. I think I may be a generation of engineers away from getting our guys really functional or accepting. But this needs to be done.
Operators		
-	-	Sorry, I had to depart at this point. Thank you for inviting me.
-	-	Who is the intended customer?
-	-	-
FAA Sponsored Researchers		
2	4	Need not perfectly clear. Work done so far to generate simulations is good progress.
-	-	-
-	-	-
3	4	Very important to support this kind of simulation and training software.
-	-	-
-	-	-
-	-	-
Other		
-	-	-
2.5	4	Useful tool. Future directions ok. Need to make simple to be successful.

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