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AFWAL-TR-88-4218

COMPOSITES INSERVICE INSPECTION SYSTEM PRODUCIBILITY

B. Jacobs, D. Hamlin, R. Peterson, R. Spinks
Southwest Research Institute
P. O. Box 28510
San Antonio, Texas 78284



15 October 1988

FINAL REPORT for Period 2 February 1984 - 15 October 1988
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1. PROGRAM OVERVIEW

The program goal was to develop an Automated Real Time Imaging System (ARIS), USAF Contract F33615-83-G-5066, under the technical direction of Mr. Edward Wheeler, Metals Branch (NDE-AFWAL/MLTM), Air Force Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. The program was to be accomplished through several phases and tasks as follows:

Phase I-Preproduction System Design and Design Verification

- Task I. Evaluation of ISIS Prototype
- Task II. Draft Preliminary Design of the Proposed Concept
- Task III. Verification of Solutions to Concept/
Configuration/Assemblies
- Task IV. Preliminary Design Review

Phase II-Preproduction System Fabrication and Evaluation

- Task I. Fabrication of a Preproduction System
- Task II. Contractor Evaluation of the Preproduction
System
- Task III. Field Evaluation of the Preproduction System

Phase III-Production System

- Task I. Fabrication of the Production System
- Task II. Contractor Evaluation of the Production System

Phase IV-Field Evaluation and Documentation of the Production System

- Task I. Field Evaluation of the Production System
- Task II. Preparation of the Documentation for the
Production System

The program followed this structure and resulted in the delivery of four production ARIS units and one preproduction ARIS unit. The preproduction ARIS unit is functionally identical to the production unit with the sole difference being that the ultrasonic instrument of the preproduction unit has not been divided into two modules as have those on the production units. The ARIS units have been field tested at several Air Force facilities on a variety of aircraft components and have been found to perform reliably and accurately.

2. PROGRAM SUMMARY

2.1 Phase I - Preproduction System Design and Design Verifications

Official contract authorization to proceed was received from the Air Force on March 16, 1984. A project in-house "kick off" meeting was subsequently held for the Southwest Research Institute (SwRI) project team to designate personnel for detailed assignments, and to discuss schedule requirements and review project objectives. At that time, preparations were initiated through the Air Force project manager to acquire one of the General Dynamics ISIS units and related documentation.

Personnel from SwRI and McDonnell Aircraft Company (MCAIR) visited McDill AFB on March 27, 1984, to observe an ISIS inspection of the horizontal stabilizer close-out area on an F-16 aircraft. This trip provided important insight into the current state of ISIS development and permitted extensive discussion with Air Force and Universal Technology personnel concerning operational features and logistical requirements of the current ISIS design.

The project "kick-off" meeting was held at SwRI between Air Force, MCAIR, and SwRI project personnel on April 2, 1984. On April 12-13, 1984, a project meeting was held at MCAIR facilities to:

- Establish specific project assignments for the ISIS evaluation and preliminary design tasks of Phase I
- Discuss the structural details associated with the composite and bonded structures used on the F-15, F-18, and AV-8B aircraft
- Observe and discuss the current MCAIR production inspection methodologies and associated instrumentation requirements
- Discuss the necessary system functional and operator interface requirements of the production ISIS.

An existing ISIS unit was delivered to SwRI from California via an Air Force transport plane. Arrangements were made to have Universal Technology personnel at SwRI on May 1-2. These personnel assisted the SwRI project team during the setup and initial stages of the ISIS evaluation and would later be instrumental in the field evaluation of the ARIS system.

Arrangements were also made at this time to acquire composite and bonded structural specimens to be used during the project, from the Air Force and MCAIR. General Dynamics had already shipped a specimen of the F-16 structure to SwRI.

The evaluation activities of the existing ISIS unit were essentially complete by May 1984. Project personnel responsible for the electronic, software, and mechanical evaluation of the ISIS finished their respective evaluations and documented their findings. The primary objective of the assessment of the existing ISIS was to identify those features considered acceptable (in terms of the performance objectives for the new ISIS

design), those features considered unacceptable or marginal, and how improvement in these less desirable features will be accomplished. The documentation of the evaluation results addressed each of these topics for each of the technical disciplines involved, i.e., electronic, software, and mechanical.

A system walk-through document was prepared for concept verification which provided a detailed description of the overall system design goals, operational modes, operator interface requirements, etc. It was written by and for the use of the project team to help assure effective and efficient coordination of the total system development effort. Two copies of this document were provided for Air Force review. In conjunction with the development of the walk-through document, design of the system software was initiated with the development of flow charts which defined the overall system software structure and the functional elements of each of the major software modules.

The software design effort started with the development of the functional and general flow charts as specified by the contract data requirements. Flow charts were developed for each program and depicted the major logic steps, operations, and flow of information. Specifically, the software documentation included 5 functional flow charts and 36 general flow charts. Additional documentation included:

- (1) Definition, explanation and documentation examples of algorithms.
- (2) Module/subroutine cross-reference index.
- (3) Module program summary block diagram.
- (4) System hierarchy structure diagram.
- (5) Diskette file structure for both parameters and processed data sets.
- (6) Definition of key variables required to permit interprogram and intermodule communication.

It was agreed previously that SwRI would provide pseudo code in lieu of detailed flow charts when documenting the system software development.

The work on Phase I was concluded in February 1985, and a preliminary design and documentation review was held on March 8, 1985. The draft preliminary design documentation provided the details of the mechanical, electrical, and software designs as well as a detailed description of the system operational characteristics, i.e., functional capabilities, operator interface requirements, and a description of each step in the inspection process (i.e., setup and assembly, real-time data acquisition, processing and display, and post processing). Approval to proceed with Phase II activities was granted after this review was completed.

2.2 Phase II - Preproduction System Fabrication and Evaluation

Component selection had been made in the preliminary design activities in Phase I, and Phase II consisted of assembling and interfacing the component within the performance and packaging constraints imposed by the client. Some effort was expended in funding replacements for components no longer available and in the design and fabrication of the probe holders and related inspection fixtures. The component selection process had resulted in selection of the:

- Equipment enclosure
- Krautkramer USD-1 Ultrasonic Instrument
- Graf Bar 8 Sonic Digitizer
- Graphics controller electronics
- Disk drive and controller
- System control and processing CPUs
- TV camera and tests
- Keyboard
- IEEE 488 interface
- PROM memory
- Texas Instruments Model 850 printer/plotter

The interface and interconnection activities required cabling and electronics to allow communication between the various modules.

The software development and implementation used the Motorola VME-10 and EXORmac development systems. The software development effort was divided into two parallel tasks. The first task involved configuring and testing the VersaDOS software driver programs which are responsible for communicating between the Fortran 77 programs and the component devices comprising the ARIS unit. These devices included the USD-1, graphics display unit, Sonic Digitizer, micro-floppy diskette, printer/plotter and the keyboard. The second task involved developing and implementing the Fortran 77 software programs required to support ARIS operational capabilities. To facilitate software reliability, this work was performed in a sequence which required the lowest level programs in the software design structure be developed and debugged before initiating work on higher level programs. Additionally, a set of graphics plot library routines based on the PLOT-10 format was developed to support standardized graphics software source code for all ARIS display software.

By December 1985, tests were completed on each of the system modules to assure that they met the vibration, shock and drop test requirements of the contract specifications. The design was completed on the test plate which is described in the System Test Plan of the preliminary Design Specification. Development of the contractor evaluation plan was initiated and the specific composite and bonded samples to be utilized during the evaluation were selected. The checkout of the USD-1 software and SwRI data interface board was completed and activities associated with implementation of the software design were continued. Lastly, a detailed analysis of the suitability of the contract survivability specifications was carried out.

By April 1986, the last task for software implementation was programming the EPROM devices required to support PROM-based ARIS operation. The ARIS unit was initially operated in a diskette-based mode and in a RAM-based mode. RAM-based operation was used to allow debugging and testing of the ARIS software to confirm proper configuration prior to the final EPROM device installation and checkout. The RAM-based testing was performed using a two megabyte memory card which was loaded from diskette. Testing in this mode confirmed proper software operation followed by the final EPROM programming activity.

The contractor evaluation was begun using diskette-based software so that proper operation could be verified before the software was loaded into PROM. The contractor evaluation consisted of:

- (1) Detection and sizing of defects in each of the seven composite and bonded structures specified in the contract technical specifications.
- (2) Evaluation of the booted transducer assembly to determine its relative effectiveness on rough and uneven surfaces.
- (3) Evaluation of the yoke and gimble assembly for through-transmission data acquisition applications. The major concern with this device, and the purpose of its evaluation, was to determine the degree of difficulty (and therefore the practicality) of maintaining adequate alignment during data acquisition activities.

Prior to initiating the formal contractor evaluation activities, the system was functionally evaluated using the test plate as described in the System Test Plan of the Preliminary Design Specification. The test plate was configured with a series of flat-bottom holes (FBH) and equipped with side brackets which precisely and repeatably position the acoustic receivers. Multiple scans of the test plate were carried out such that comparison of the test results with the known hole depths and locations assured that all system functions were performing repeatably within acceptable tolerances.

In addition to the performance evaluation tests on T-38 wing tip parts and horizontal stabilizer data was also successfully obtained using composite samples of the F-16 horizontal stabilizer torque box region, the F-15 rudder, C-141 leading edge section, and the missile fin sample.

The contractor evaluation activities to determine the functionality and ease-of-use of system hardware and software were essentially completed in January 1987. On January 20, 1987, a project meeting was held at SwRI to review the overall project status and schedule; and to discuss the specifics of the completed preproduction system design, to review the contractor evaluation data acquisition results and to familiarize and train Universal Technology personnel in the use of the system. Also discussed during the meeting were plans for the first field evaluation trip to Edwards AFB.

The first system field evaluation activities were carried out at Edwards AFB during February 2-13, 1987, at both NASA and Air Force facilities and included various types of composite and bonded structures on a variety of aircraft types. The specific aircraft structures included complete upper right wing skin of the X-29 and selected areas of the lower right wing skin. A pulse-echo inspection was conducted on the X-29 wing skins which are constructed of graphite/epoxy material of varying thickness and mechanically fastened to a metal, rib-type substructure. Several small areas of suspected porosity were recorded and a small delamination near a fastener hole, previously found visually, was verified and determined to have not grown in size since its original detection.

Other types of structures addressed during this trip for which the use of ARIS appeared suitable were:

- T-46 main landing gear doors (through-transmission) and rudder (pulse-echo).
- B1-B weapons bay door (through-transmission).
- F-16 dorsal fin (through-transmission).
- F-15 horizontal stabilizer (through-transmission).
- F-18 vertical stabilizer torque box and leading edge (pulse-echo).

All of the data obtained during the Edwards AFB trip were archived on micro-floppy diskette for future reference or comparison requirements.

A second ARIS field evaluation trip was conducted at Randolph AFB in March 1987, and various mechanical and software modifications were either initiated or completed in response to action items identified during the previous field evaluation activities. The ARIS evaluation activities at Randolph AFB were carried out on various types of composite and bonded structural configurations used on the T-38 including wing tips, horizontal stabilizers and ailerons. Pulse-echo inspections were successfully conducted on several composite wing tip structures and through-transmission inspections of a horizontal stabilizer and a conventional wing tip were also successfully carried out.

A third ARIS field evaluation trip was conducted at Hill AFB in April 1987, and various mechanical modifications were completed in response to action items identified during the previous field evaluation activities. In this time frame, the detailed engineering design was completed for the division of the single chassis USD-1 instrument into two separate units. The Hill AFB field evaluation activities were carried out on the F-16 horizontal and vertical stabilizers and the rudder. Through-transmission inspections were successfully conducted on honeycomb substructure portions of the horizontal stabilizer and rudder. Also, an area on the lower left side of the vertical stabilizer torque box was inspected using the pulse-echo technique. This latter inspection produced a number of indications which coincided with rows of fasteners where composite skin is attached to aluminum rib and spar-type substructure.

Color prints of the ARIS data were provided to Hill AFB NDE personnel who provided disposition of the indications.

Another ARIS field evaluation trip was conducted at Charleston AFB. At this time the USD-1 repackaging design was completed, as well as fabrication of the redesigned position receiver assembly. Additionally, an ARIS unit was shipped to WPAFB for further evaluation activities. The Charleston AFB field evaluation activities were carried out on the C-141 wing leading edge and top and at various locations on the cargo doors. The leading edge and wing top scans were carried out by monitoring the skin back surface reflection. Where internal stiffeners were bonded, the back reflection was expected to disappear as the sound continued into the stiffener. The pattern of the data generally verified this expectation. Some data obtained during this inspection suggested possible disbonds or delaminations which would require a more detailed evaluation to resolve than could be carried out at the time of the ARIS evaluation activities.

The system was also used to inspect composite cargo doors on two different aircraft. The first door inspected had a very porous surface texture due to an outer layer of rough, unfilled, fiberglass cloth. No ultrasonic signals could be received from this structure, even with increased receiver amplification. A second cargo door on a different aircraft was inspected using the same technique used previously on the first door, with good results. The surface texture of this door was relatively smooth and sound transmission into the part was accomplished without difficulty.

The field evaluation of the preproduction system was completed by August 1987. A total of five different bases were visited and a variety of components were examined during the evaluation. The findings were incorporated into hardware and software modifications in the production units.

2.3 Phase III - Production System

Phase III, Production System, began with the preparation for the Final Design Review meeting which was held at Wright-Patterson AFB on August 7, 1987. The comments and experience gained from the field evaluation have been incorporated into the final design and were discussed in the meeting. In this meeting, all aspects of the final system design and performance were reviewed and compared to the original design objectives and performance specifications. With this sole exception of the 40-pound weight limitation for all system modules, the system meets or exceeds all design and performance specifications.

The major fabrication concern was the splitting of the USD-1 ultrasonic instrument into two modules for ease of portability and weight considerations. The instrument was converted into two modules at SwRI because the manufacturer declined to do it. Delivery of the instruments was also a concern, all four instruments finally being received by September 1987.

During this period (August-September 1987), fabrication of the system mechanical hardware was completed. This consisted of the control

unit, power supply module, split USD-1 chassis, sound bar, probe assembly, through-transmission yoke, handle and block-type probe holders. The electrical fabrication of the control units was completed as well as the external cabling, interconnection cabling and search unit cabling.

By December 1987, all work on modifying the USD-1 instruments was complete. Operational checkout of the various system modules (ultrasonic display unit, ultrasonic digital control unit, power unit and control units) was completed as well. The four production units were assembled in the final configuration for delivery except for installation of the PROM-based system software which took place in January 1988.

One ARIS production unit was sent to Wright-Patterson AFB in February 1988 for preliminary evaluation prior to the field evaluation. The purpose of this evaluation was to allow the opportunity for the concerned Wright-Patterson AFB and Universal Technologies staff to review and exercise the various modifications which had been incorporated into the units prior to actual field evaluation. This evaluation was part of the contractor evaluation under the scope of Phase III. The system was returned in April 1988 for an upgrade of the PROM-based system software.

The activities associated with production unit fabrication and contractor evaluation were completed by March 1988.

2.4 Field Evaluation and Documentation of the Production System

The first of four production ARIS units was delivered in mid-February 1988 to the AFWAL Material Laboratory at Wright-Patterson Air Force Base (WPAFB). All aspects of setup, operation and packaging of the unit were subsequently evaluated and detailed comments were made in writing to Southwest Research Institute. All comments on the pre-production unit had been resolved with the first production unit, and all comments on the pre-production unit had been resolved with the first production unit, and all comments on the latter unit had been subsequently resolved on all production units.

As part of the evaluation plan for the ARIS production units at various Air Force bases, three sets of panels were prepared at WPAFB. Each set is comprised of six panels:

- (1) A graphite epoxy laminate, approximately 0.480 inch thick, containing simulated delaminations at regular intervals of thickness.
- (2) A small section of non-metallic composite structure, made for the outer skin of the C-141 cargo doors, with some flat-bottom holes drilled into the back.
- (3) A 0.375 inch thick graphite epoxy panel with impact damage intentionally inflicted in a controlled manner.
- (4) A two-foot square section of the C-141 cargo door material also impacted in a controlled manner.

- (5) A 0.125 inch thick graphite epoxy panel with intentionally applied defects of the type which have been found during fabrication of fiber reinforced plastic laminates.
- (6) Either a 0.180 or 0.250 inch thick aluminum panel with ground out areas on one side simulating corrosion/erosion.

Inspection techniques were developed for each type of panel, and each panel was scanned with an ARIS unit at WPAFB. One set of panels has accompanied each of the three ARIS units delivered to date to Air Force bases. The respective parameter set and data file for each panel were also provided.

The panels provide known entities to help operators become familiar with the ARIS. The successively generated data files for each panel also provided a measure of the reproducibility of the ARIS. The parameter sets served not only to allow a new operator to begin scanning something quite soon, but also provided a series of somewhat generic starting points for operators to develop inspection techniques for other test articles. The WPAFB data files provided the new operator with a basis of comparison for his data, giving him feedback on his operation of the ARIS and an opportunity to actually use the comparative analysis feature of the ARIS. To carry the comparative analysis one step further, the aluminum panel was altered after the scan at WPAFB in order to simulate a real-life situation of defect growth when the panel is subsequently inspected at an Air Force base.

With each ARIS delivery Universal Technology Corporation (UTC) personnel traveled to the respective Air Force bases to familiarize Air Force personnel with the ARIS features and capabilities. The UTC personnel also trained designated operators to set up and use the ARIS. Assistance in generating additional parameter sets was also provided to accommodate specific structures peculiar to each base.

2.4.1 Sacramento ALC

An ARIS was delivered on 16 May 1988 to SM-ALC/MAQCA, McClellan AFB, CA 95652-5149. The parts on which the ARIS has worked include the SR-71 radome, typical stiffener runout areas inside F-111 metal wing structures, an F-111 composite engine bay door strake and a composite F-111 tank fin. Success with the SR-71 radome prompted plans to take the ARIS to other bases to satisfy a current need to inspect those radomes. An on-site modification was made to the position receiver assembly so that a strap around the irregularly shaped radome could be used to hold the assembly in place during an inspection.

2.4.2 Ogden ALC

The second ARIS delivery was made on 27 June 1988 to 00-ALC/MAQCM, Hill AFB, UT 84056-5149. In contrast to Sacramento ALC, the personnel assigned to become the ARIS operators were slower in becoming adept at operating the system. This was due mainly to their limited experience with microprocessor controlled equipment. It was two to three weeks after the three days of training before they were satisfied with

their understanding of the ARIS operation. However, since then they have been using the system regularly on F-16 composite components: horizontal stabilizers, vertical stabilizers and ventral fins. Through-transmission, pulse-echo and resonance techniques have been used. Some inspections of patched areas have also been accomplished.

2.4.3 Oklahoma City ALC

The third ARIS was delivered on 25 July 1988 to OC-ALC/MMETM, Tinker AFB, OK 73145-5990. During the training period, the ARIS was successfully demonstrated on a B-1 weapons bay door. Since that time, the personnel have thought of several applications for the ARIS and are trying to get access to specific aircraft components. Meanwhile, some time has been spent scanning the specimens delivered with the ARIS.

The documentation for the production ARIS is completed. The mechanical and electrical drawing packages were completed in April 1988, as well as the software documentation. In May 1988 the Production Unit Specification and the system Test Plan were completed. The remaining documentation was submitted in October, 1988.

3. ARIS SYSTEM DESCRIPTION

3.1 General Background

3.1.1 Design Objectives

The ARIS technology is based on the principle of simultaneously recording ultrasonic inspection data along with the ultrasonic search-unit position during a manually scanned inspection. During the scan, the search-unit position is continually monitored using an acoustic ranging subsystem. This subsystem transmits time-of-flight information to the central processor which, in turn, calculates position by triangulation calculations. Other important design goals were a maximum 4' by 4' coverage plot and the ability to accommodate curved surfaces. These were met by operator generated inspection templates and the incorporation of a radius-of-curvature parameter in the software. The validity of these principles was demonstrated by field trials with the prototype unit from the previous developmental program. The practical application of that technology is now dependent on addressing the specific needs of the inspector: complexity of setup, setup and inspection time, flexibility, and portability. These factors are important to the success of any field inspection activity. With automated data collection features, there are the additional requirements of the system to collect, store, and process the large amounts of data in a convenient way. The convenient use of these data is the key ARIS technical benefit, as ARIS images acquired during different stages of aircraft life can be compared with each other and with production images to monitor flaw growth. The ARIS development program specifically addressed establishment of a system that is efficient in the field inspection environment.

The principal objectives of the technical approach were:

- (1) Establishment of a transportable system based on a modular assembly.
- (2) Establishment of a high productivity system with features such as:
 - Electronic template for defining, within the inspection area, zones with similar inspection requirements with a 4' x 4' maximum coverage.
 - Simplified operational software based on the use of high-level commands of a type familiar to the average inspector.
 - Remote display and control capability for convenient inspection-system interaction.
 - An adaptable search-unit assembly configured for use with standard transducer types and transducer coupling systems.

- (3) Establishment of an affordable and producible system based, for the most part, on commercially available elements.
- (4) Establishment of a flexible system with features such as:
 - Processor-controllable ultrasonic instrument compatible with inspection requirements of advanced composite and bonded structures.
 - Modular position-locating assembly.
 - Modular software structure adaptable to advanced flaw detection and characterization methods.

Each of these objectives was satisfied by the ARIS design, the details of which are presented in the following sections.

3.2 System Overview

(15)
P 10
The ARIS provides automated, simultaneous recording of ultrasonic data and search-unit position information during a manually scanned inspection of composite and bonded aircraft structures. The system is designed for easy portability, fast on-site setup, high productivity, and operation by a single operator. The operational requirements of the system are such that the operator need have only an ultrasonic nondestructive evaluation (NDE) background equivalent to that normally required of an ASNT SNT-TC-1A certified Level I examiner (i.e., knowledge of basic concepts and ability to perform a calibration and other specific tasks according to written instructions). Site-support requirements for the system are limited to providing electrical-power hookup at the inspection site and a means of elevating the operator to inspection locations on the aircraft not inspectable from ground level. A pictorial overview of the system and a system block diagram are shown in Figures 3-1 and 3-2, respectively.

3.2.1 Principal System Features

(1) Convenient Portability

ARIS is designed to be conveniently portable such that the system can be shipped as airline baggage. The entire system is shipped in 13 suitcase-sized enclosures.

(2) Fast On-Site Setup

Following arrival on-site, inspection preparation begins by assembling a mobile cart shipped with the system. When assembled, the cart serves as an equipment rack and a means for maneuvering the system around the inspection area, as shown in Figure 3-3. When disassembled, the cart converts into its own shipping enclosure.

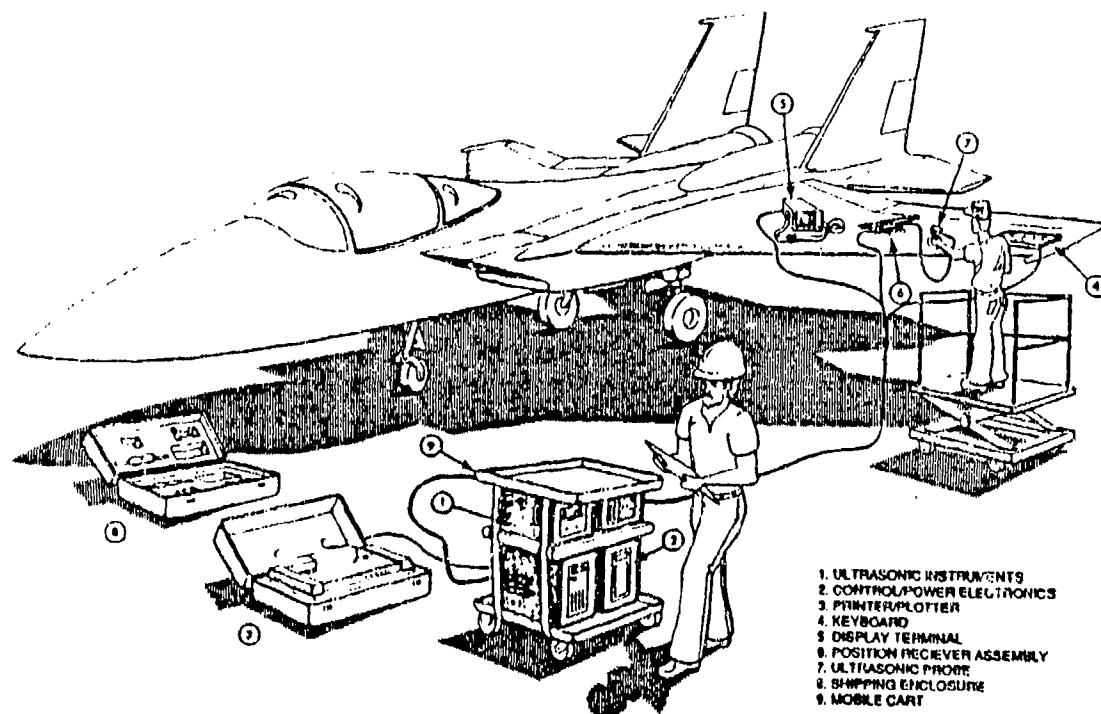


Figure 3-1. ARIS conceptual overview

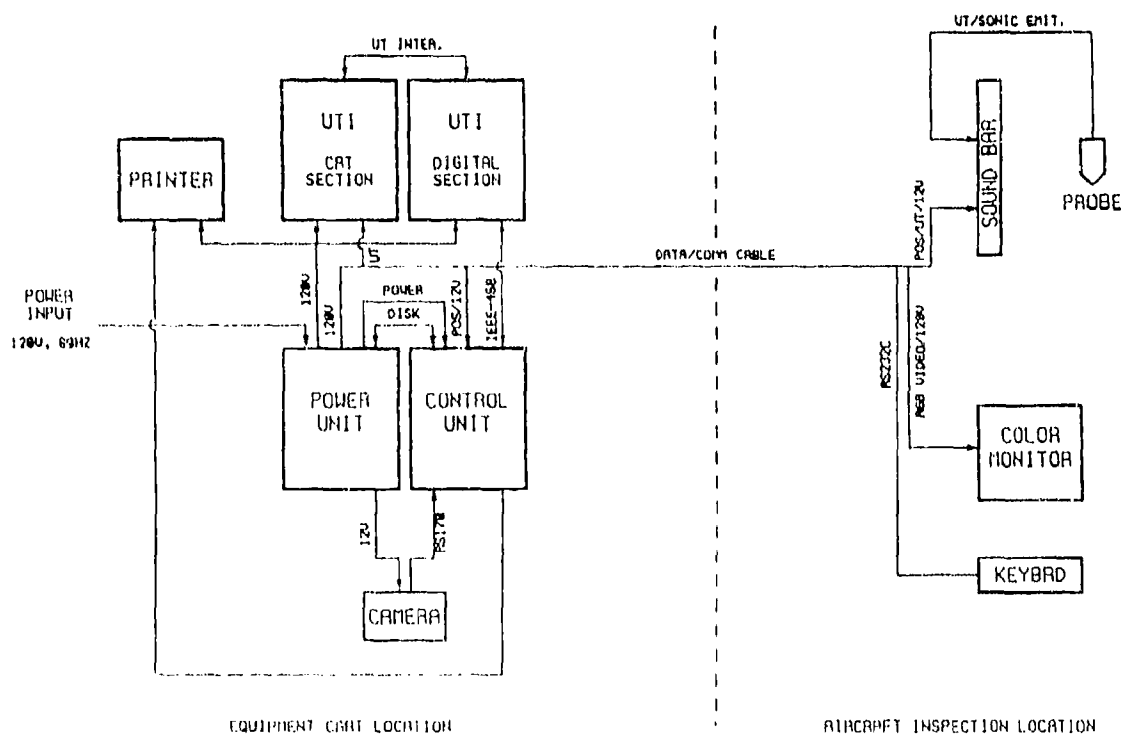


Figure 3-2. System block diagram

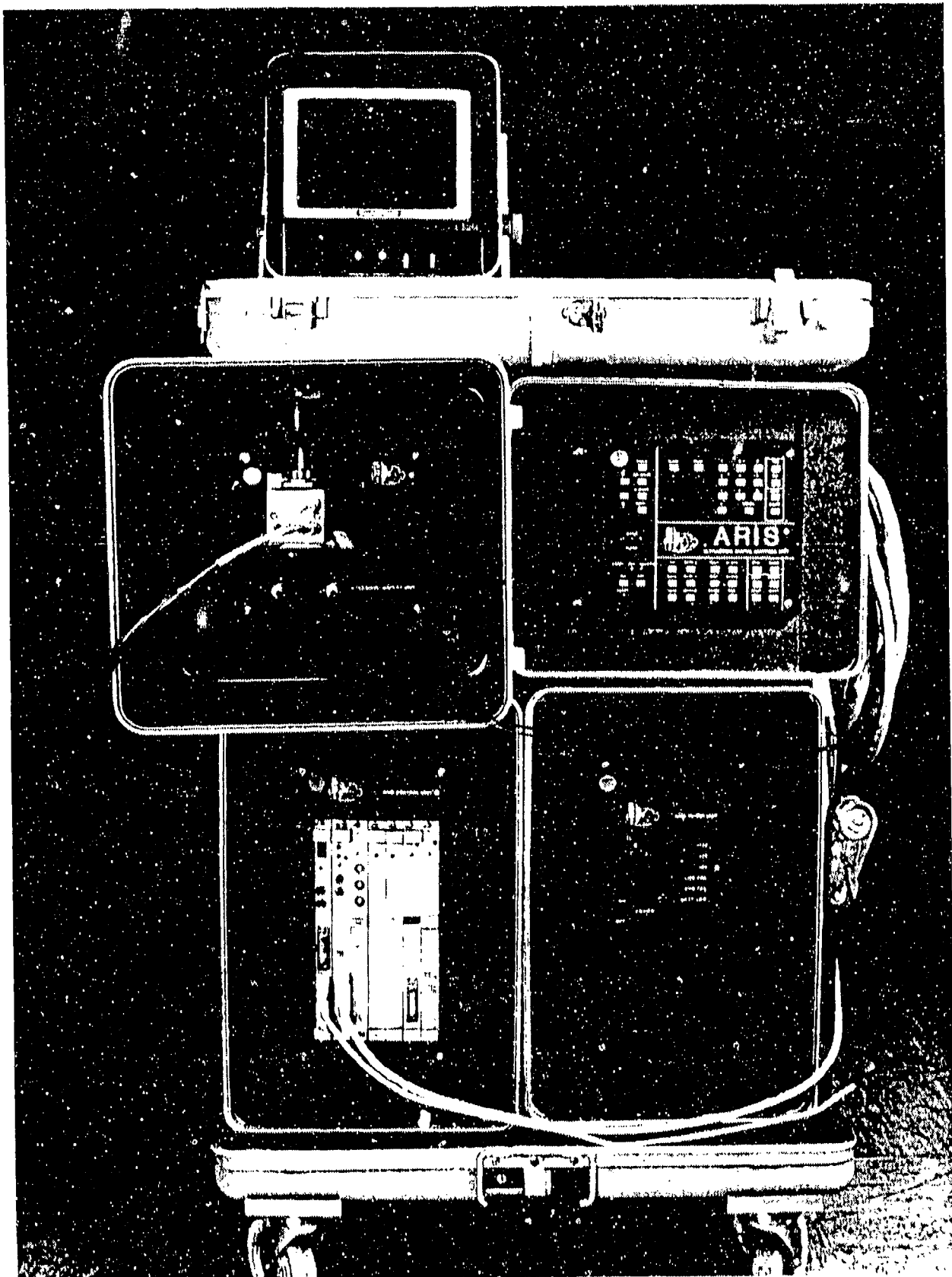


Figure 3-3. System assembled on its mobile cart

On-site setup is a six step procedure:

- (a) Assemble the mobile cart. The shipping enclosures of the UT instrument, power supply, and control electronics units are an integral part of the mobile cart assembly. These units remain in their shipping enclosures and are readied for use by simply removing the enclosure end panels.
- (b) Install miniature television camera in front of the UT instrument. The camera is mounted on the hood enclosure attached to the UT instrument display-scope shipping enclosure. When positioned in front of the oscilloscope, A-scans may be viewed on the system display unit.
- (c) Place the remote inspection equipment (i.e., display unit, position receiver assembly, and keyboard) on top of the mobile cart and connect the system cabling.
- (d) Assemble the inspection stylus with the desired transducer and delay-tip attachment, and connect the probe cable to the position receiver assembly.
- (e) Connect printer, if desired. ARIS can operate without the printer being connected to the system.
- (f) Connect the system to the external power source.

With the completion of steps (a) through (e), setup is complete, and the system is ready for checkout and parameter entry.

(3) Automated Checkout and Parameter Entry

The ARIS software is designed to provide convenient system operation in that as little as possible is required of the operator in assuring that the system is functioning properly and in entering inspection parameter values. Where operator input is required, the operator is led by an easily understandable set of instructions presented on the display unit in a menu-type series of selections and prompts, which in most instances limits operator action to touching a single keyboard key. Control programs, providing the operator guidance and selections, are EPROM resident and, therefore, do not require diskette loading.

System checkout and parameter entry are carried out as follows:

- (a) Power-up the system.
- (b) Select the system checkout module. With the selection of this software module, the operator can initiate device status checks which determine that all components have been powered and correctly connected to the system. Device operational tests can then be carried out for each component to assure proper operation.
- (c) Enter the inspection identification parameters; i.e., aircraft number, component identification, structural type, materials, etc.
- (d) Enter the UT instrument parameters; i.e., gain, pulser voltage, threshold amplitude, gate locations, etc.
- (e) Enter the data processing parameters defining how data will be processed and displayed during the inspection.
- (f) Enter the inspection boundary or template data which the display unit presents relative to target-point locations on the inspection surface. All of the entries required in steps (c) through (f) can be input into the system automatically from diskette if they were generated off-site previously or existed from a previous inspection of the same or a similar part. In these cases, the parameter values (e.g., UT calibration values should be very similar to those needed and therefore require only minor adjustment) or identification information need only be modified to reflect the specific inspection taking place.

(4) Processor Control of All System Functions

Unless the inspection procedure specifies otherwise, an inspection is carried out in the full processor-control mode. In this mode of operation, the processor controls all components, including the UT instrument and all system functions (e.g., synchronization, real-time data processing and display, etc.).

(5) Remote System Control and Display

At the location on the aircraft at which the operator is performing the inspection, a light-weight display unit for all menu, parameter, and data-display functions is provided. If during the inspection, the operator wishes to pause, modify the instrument settings (e.g., gate width, gain, threshold level, etc.), view the A-scan presentation from the oscilloscope, etc., any of these activities may be carried out at

the inspection location on the aircraft by use of the keyboard. The system has complete remote control through the keyboard.

(6) Data Display and Presentation Flexibility

The operator may select any one of several modes of flaw data display; that is, flaw display on a go-nogo basis (i.e., the flaw indication is displayed without regard to any distinction between flaw signal responses) or on the basis of color by depth or color by amplitude. The go-nogo display is applicable to both pulse-echo and through-transmission; color by depth is used with pulse-echo, and color by amplitude would normally be used with through-transmission. The color displays would usually be preferable to go-nogo displays, since the color variation (16 colors are available) provides an additional dimension of information to the operator concerning flaws, and may reveal details about the substructure that should enhance the operator's efforts to conduct a thorough inspection.

At the beginning of an inspection, the region within the scan boundary is displayed on the CRT screen. As the inspection progresses, the system automatically updates the display (i.e., changes the color) for those locations corresponding to where the operator has thus far inspected. For go-nogo threshold displays (whether positive or negative logic), three color intensities are used corresponding to (1) no coverage/couplant, (2) coverage but no signal data, and (3) coverage with signal data (threshold violation). For color by depth or amplitude displays, the color levels correspond to (1) no coverage/couplant, and (2) a color level corresponding to the amplitude or depth of the detected signal. In this manner, when the color levels of all the original data have been properly updated, the inspection is complete and the operator is assured that no portion of the inspection region has been missed. Simultaneously, any flaws detected will be displayed in real-time, thereby, providing the operator immediate feedback on the results of the inspection as it progresses.

Another very useful display available to the operator during an inspection is the A-scan presentation of the oscilloscope. This display, of course, is directly available to the operator whenever he is at the ultrasonic instrument. However, the need to view an A-scan usually occurs during the course of an inspection while holding the inspection probe at a specific location(s) on the surface of the aircraft. In these instances, the operator can "call-up" the A-scan on the remote display screen. If the operator desires, he may interrupt the inspection sequence and record the A-scan data and store it with the other inspection data.

(7) Hardcopy Documentation

Following an inspection, all of the above displays (i.e., go-nogo, color by depth, color by amplitude, and A-scans) may be produced in hardcopy. The display coverage/flaw map serves to document that the entire inspection region was covered. A tabular printout of the inspection results (calibration parameter values, identification information, etc.), can also be produced.

(8) Specially Designed Inspection Probes

Inspection probes have been designed with significant attention given to:

- (a) Operator comfort (minimizing hand fatigue),
- (b) Fast scan coverage,
- (c) Fast search unit/delay-tip changeout,
- (d) Scan coverage of irregular surfaces (due to denting, chipped paint, etc.), and
- (e) Through-transmission scan capability.

(9) Modular Hardware and Software

The ARIS hardware is packaged and functions on a modular basis. The modular hardware approach facilitates portability, trouble-shooting, replacement, etc. Also, with the exception of the cabling, inspection probes, mobile cart, and data-interface circuit, all system components are commercially available. The modular software design facilitates software modifications and upgrade. Each of the principal system features noted above is discussed in detail in later sections.

3.2.2 Portability and Weight and Packaging Analysis

(1) Portability

Portability was a major consideration during the design of the ARIS. The specific goal was to package the system such that, when shipped, no single enclosure would weigh in excess of 40 pounds, and that the sum of the length, width, and height of any enclosure would not exceed 62 inches. Although the total number of enclosures required to ship the system was not limited, consideration was given to packaging the equipment as efficiently as possible to minimize the number of enclosures used.

A major difficulty in meeting the enclosure weight and size limitations was the stringent requirements of Military Specification IAW-MIL-T-28800B, which significantly impacts the enclosure design. The survivability requirements imposed by this specification dictate the use of heavy-duty shipping cases with substantial internal shock-absorbent materials. These, by necessity, have a major impact on size and weight of the enclosures when shipped, e.g., on the average, the protective cases and shock-absorbing materials constitute approximately 40 percent of the weight and 30 percent of the size of each system enclosure when shipped.

Of the 13 enclosures required for shipment of the system, only one exceeds the 62-inch size limitation; and the average weight of all enclosures is 38.3 pounds. The size and weight of each enclosure are shown in Section 3.2.2(2), Weight and Packaging Analysis.

The Krautkramer-Branson USD-1, selected as the ultrasonic instrument for the ARIS, weighs 40 pounds as purchased. The weight of the protective enclosure and shock absorbent materials in which the unit is shipped is approximately 30 pounds, resulting in a total estimated weight of 70 pounds. To meet the 40-pound weight limitation (approximately), the unit has been divided into two separate enclosures. Significant modifications by SwRI to the purchased instrument were accomplished while still maintaining the original performance and reliability.

On-site portability, i.e., the ability to easily maneuver the equipment around the aircraft being inspected or to other relatively nearby locations, is also an important consideration. To assure that this capability will be conveniently available at all locations to which the system is shipped, a mobile cart (see Figures 3-1 and 3-3) is provided as a piece of standard system hardware. The cart is designed for fast assembly and disassembly. The cart parts in the disassembled state form a traveling case for ease of transport and shipping. Also, a one-piece, pull-down cover is provided to protect the cart-mounted equipment from direct exposure to inclement weather conditions.

(2) Weight and Packaging Analysis

Enclosure (Letter Identifiers Shown)	Contents	Dimensions L + W + H (in.)	Total Dimensions (in.)	Weight (lbs)
UT1	UT Digital Control	26.5 + 15.6 + 13	55.1	47
CT2	UT Display Scope	26.5 + 13.75 + 13	53.25	46
PS3	Power-Supply Unit	26.5 + 13 + 20	59.5	59
MP4	Micro-Processor Control	26.5 + 13 + 20	59.5	51
SB5	Sound Bar Assembly	28 + 12.6 + 10	50.6	22
TT6	Through-Transmission Yoke	28 + 12.6 + 10	50.6	20
CM7	Color Monitor	25.3 + 19.3 + 17.2	61.8	54
RC8	Remote Camera	17.5 + 13.75 + 13	44.25	20
CC9	Control Cables	18 + 18 + 12.5	48.5	42
KB10	Keyboard	18 + 18 + 12.5	48.5	39
P11	Printer/Plotter	20.5 + 18.5 + 10	49	30
T12	Tripod	45 + 9 + 9	63	24

Total Weight - 498
Average Weight - 38.3

3.3 System Design

3.3.1 Major Hardware Elements and Components

The major elements of the ARIS are the ultrasonic instrument, system control unit, and power supply unit. The major peripheral elements consist of the remote monitor, keyboard, position receiver assembly, probe assembly, and printer. A collapsible, self-contained portable cart is provided with the system to hold the electronics equipment during use and movement in and around the job area. The functionality, component selections, and interface requirements of each of these major elements and peripherals are discussed in more detail in the following paragraphs.

All of the major system components selected for use in ARIS are commercially available.

(1) Ultrasonic Instrument

The ultrasonic instrument selected was the Krautkramer-Branson Model USD-1. This unit is divided and then packaged within two protective enclosures with removable front and rear covers to allow access to operator controls and interface connections.

The main functions of the USD-1 are to initiate the transducer excitation pulse, gate, amplify the resulting ultrasonic echoes for visual display on its CRT screen, and provide output data in the form of peak-echo signal amplitude within the desired gated time region and the time of flight (TOF) to the first signal exceeding a pre-established threshold. These data can then be acquired, analyzed, and processed by a separate computer system. The USD-1 is ideally suited to automated inspections, since it is designed for remote computer control through an IEEE-488 standard interface communications port. Instrument calibration parameters appropriate for a specific aircraft part to be examined are down loaded from the system control unit into the USD-1 without the need for manual instrument set up. The required USD-1 interface cable connections are as follows:

- (a) 120-VAC power obtainable from the power-supply unit or other source
- (b) IEEE-488 communications line to the system control unit for USD-1 control, timing, and parameter entry and verifications.
- (c) Data output port connected to the system control-unit data-interface board. The data output port provides peak signal amplitudes in analog form for gated regions A and B, and TOF

data in byte serial format for each gated region.

(2) System Control Unit

The system control unit is packaged in a manner similar to the ultrasonic instrument. A pictorial view of its front and rear panels with the case end covers removed is shown in Figure 3-4. Its major elements consist of a 68,000 based multi-processor VME compatible microcomputer subsystem, a 3-1/2-inch floppy disc drive, a CCD camera control unit, video relays, sonic digitizer board, and a data interface board. The control-unit block diagram shown in Figure 3-5 indicates the relative interconnection of each of these elements. A functional description of each of these elements follows:

(a) VME Microcomputer. The microcomputer interfaces with the user through the system keyboard. It controls the UT instrument, data acquisition, and data processing and generates video-display graphics images and hardcopy printout, as well as archival data storage on magnetic-disc media. Seven plug-in circuit boards comprise the microcomputer. Their functions are from left to right, as indicated on the control unit block diagram, Figure 3-5:

- CPU - This 68000-based microprocessor is responsible for I/O functions and general system control and provides two RS-232-C communication ports. One of these ports is used for connection to the optional printer. In addition, its P2 connector contains a 16-bit parallel I/O port which will be used for acquisition of UT data, position data, and control of the video relays.
- CPU - This 68010-based microprocessor is responsible for data processing functions and display generation. It includes an RS-232-C port, which is used for interfacing to the keyboard.
- Graphic Control - This board provides the graphics control functions and contains the memory. It controls screen data transfers between the data processing CPU and the graphics memory area and controls timing, sync, and video signal generation. This

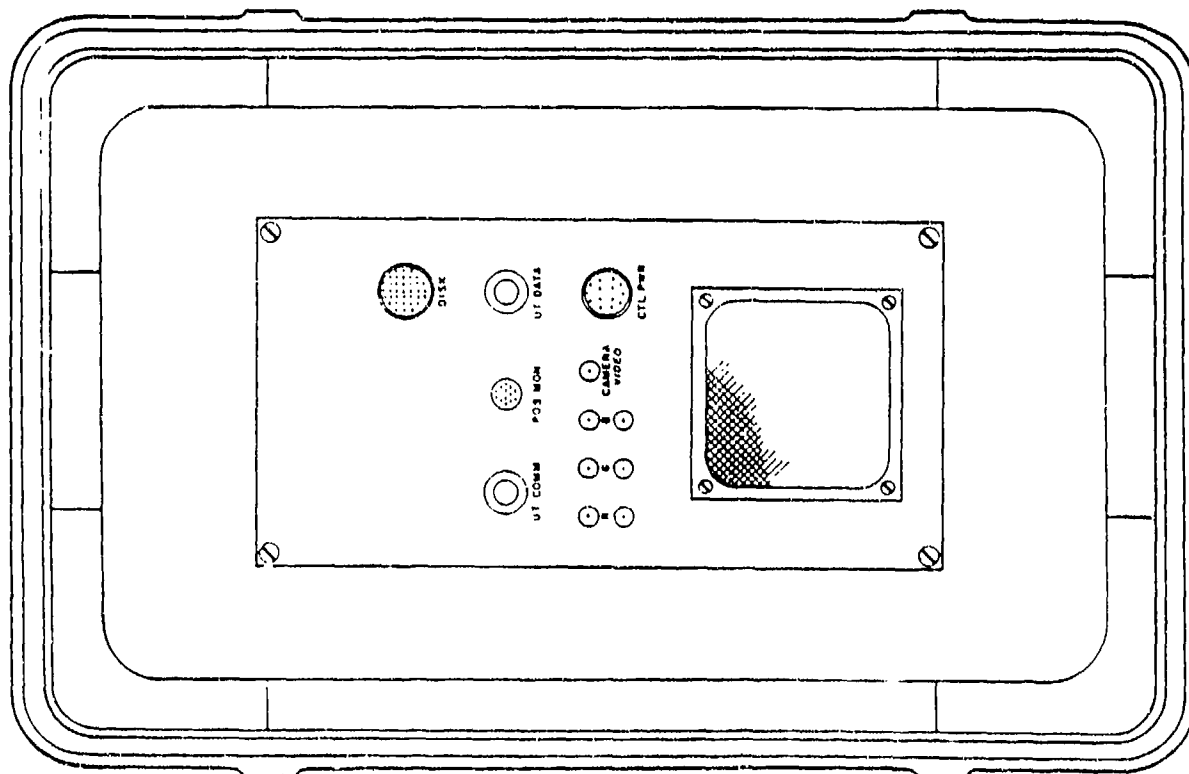
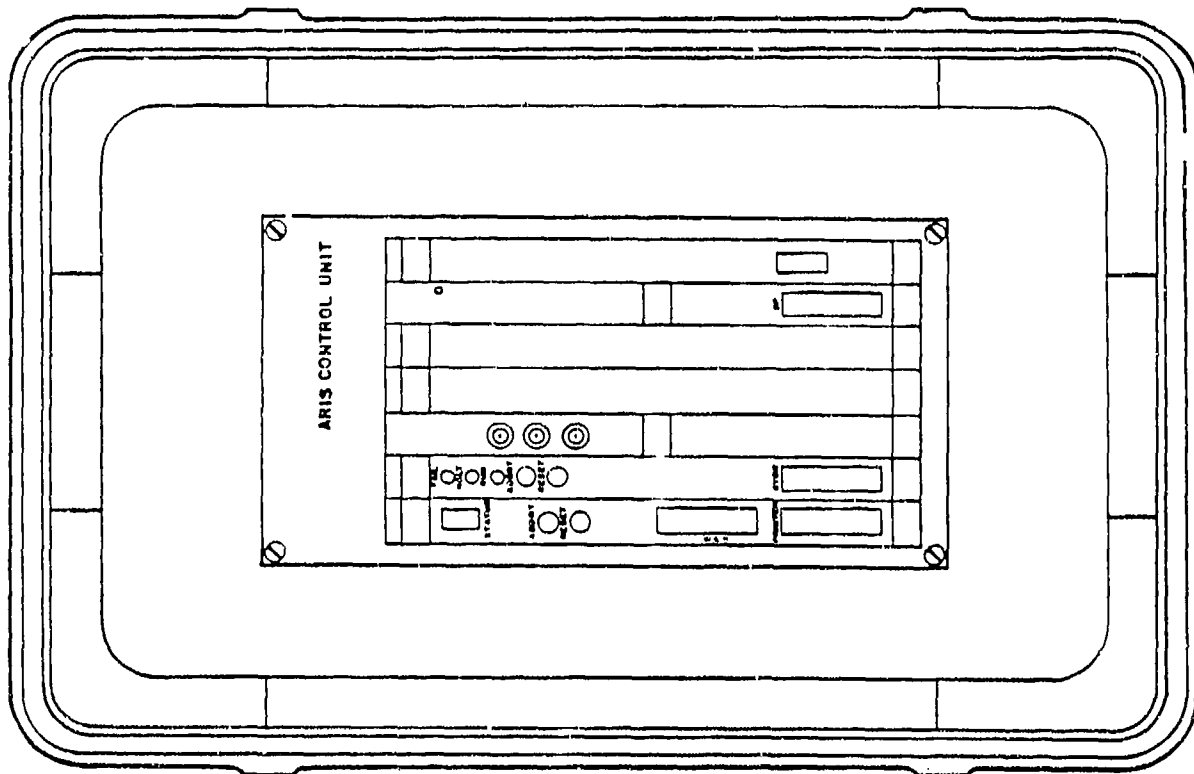


Figure 3-4. Control unit chassis

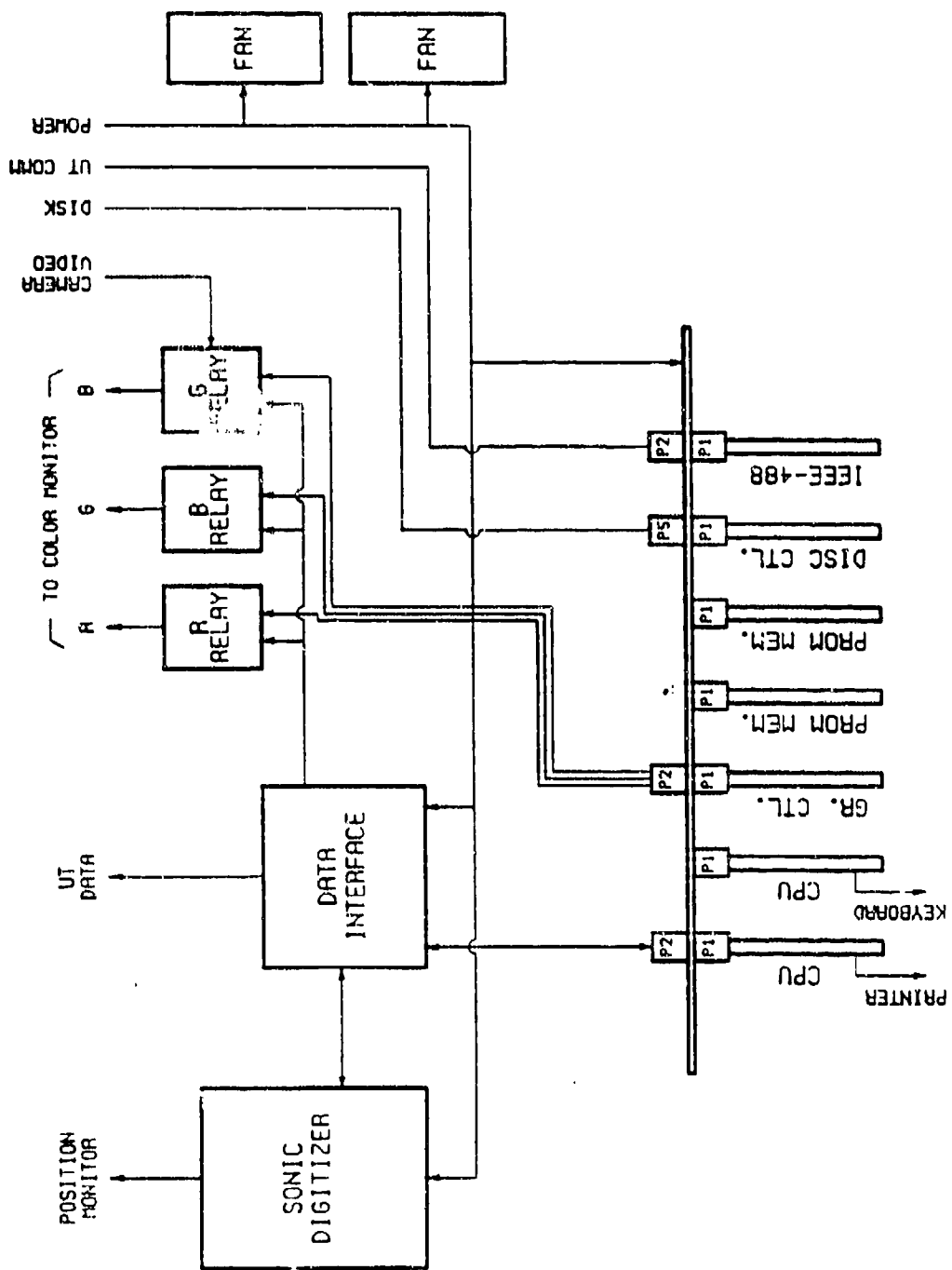


Figure 3-5. Control unit block diagram

board is capable of generating 64 colors to an RGB monitor. However, for the ARIS application, only 16 color levels can be displayed on the monitor.

- PROM Memory Cards - These cards contain the entire ARIS software control program. Portions of this program are accessed by the two CPU boards as needed.
- Disc Control - This board controls data transfer and storage to and from the floppy disc drive.
- IEEE-488 - This board interfaces to the IEEE-488 Bus connected to the UT instrument. It formats and receives data transfers compatible with this standard.

(b) 3-1/2-Inch Floppy Disc Drive. The functions of the floppy disc drive include initial system boot up and data storage and retrieval. The 3-1/2-inch form factor was selected for its small size, light weight, and rapid random access time, which makes it far superior to a magnetic tape unit. The disc drive is controlled by the disc controller board and receives +5, +12V power from the power interface board.

(c) CCD Camera Control Unit. The CCD Camera is normally focused on the front of the UT instrument CRT screen. It processes the image data into a composite video signal which is sent to the relay located within the green video control unit. The +12 VDC power for the camera is obtained from the power unit. The video input connection for the camera coax cable is located on the rear of the control unit.

(d) Video Switch. Three video relays receive the computer-generated information and graphics images in RGB format from the graphics controller board. The composite video signal from the remote camera is also received by the green relay. The operator, through one of the keyboards, can select either the computer or camera output for presentation on the remote monitor. A relay control signal generated by the first CPU is routed to a transistor buffer located on the data interface board. The output of the video switch relay is cabled to the rear panel.

- (e) Sonic Digitizer Board. The sonic digitizer board initiates the piezoelectric sonic-emitter pulse and receives sonic time-of-flight signals from each of two microphones mounted on the position-receiver assembly. The digitizer board measures the time-of-flight of these signals and transfers this information to the data-acquisition interface board for eventual acquisition by the microcomputer. From this time-of-flight information, the microcomputer determines the location of the ultrasonic transducer probe.
- (f) Data Interface Board. The data interface board receives the digitized time-of-flight information (for probe position determination) from the sonic digitizer, and the ultrasonic analog amplitude signals and digital ultrasonic time-of-flight signals from the UT instrument. It performs A/D conversion of the UT amplitude signals and holds all information in digital form for eventual acquisition by the microcomputer in multiplexed fashion. It also contains a transistor buffer for driving the video relays under control of the microcomputer. This board receives 5V, $\pm 12V$ from the power unit.

(3) Power Supply Unit

The power supply unit contains the DC power supply, uninterruptible power supply, four battery modules, disk drive, and two cooling fans. It is packaged in a protective outer case identical to the control unit's outer case with removable front and rear end covers. A drawing of its front and rear panels with the case end covers removed is shown in Figure 3-6. The DC supply provides 5V/50A and $\pm 12V/6A$ for use by the system control unit. Each of the DC voltage outputs have LED indicators associated with them on the front panel for on/off status verification by the user. In addition, five auxiliary 120-VAC plugs are available on the rear of the unit for use by other system components. Also, a clearly identified chassis ground screw is located on the rear of the unit for the purpose of attaching an aircraft safety grounding strap to the system equipment. Figure 3-7 shows a detailed block diagram of the power-supply unit.

(4) Ultrasonic Probe/Position Sensing Assembly

(a) Ultrasonic Probe Design

In designing the ultrasonic probe, significant attention was given to operator comfort and to simplicity of assembly in addition to the functional requirements of the inspection. The probe is used to carry out two functions simultaneously, transmission of a high-frequency (megahertz) signal into the aircraft structure for defect

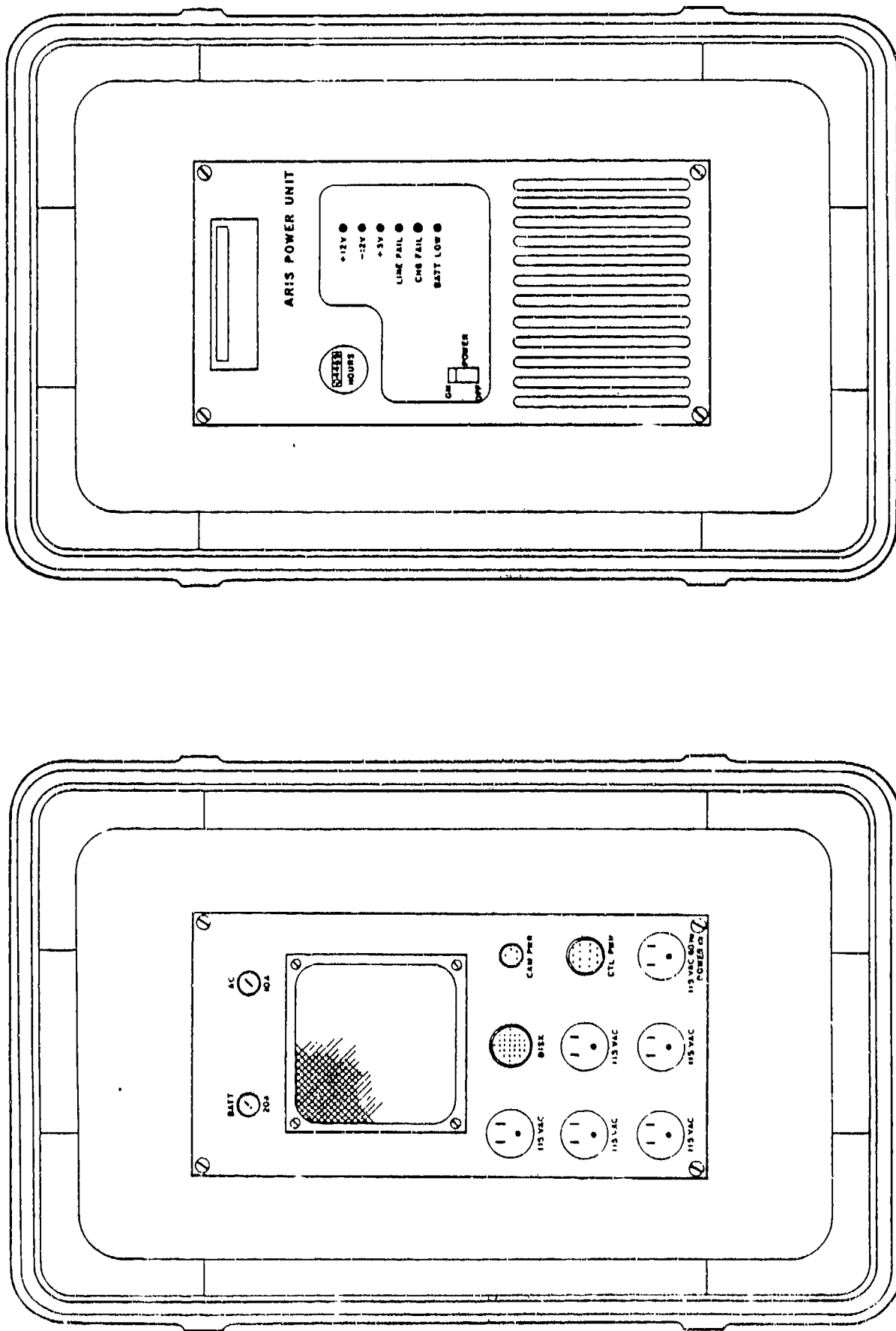


Figure 3-6. Power unit chassis (landscape)

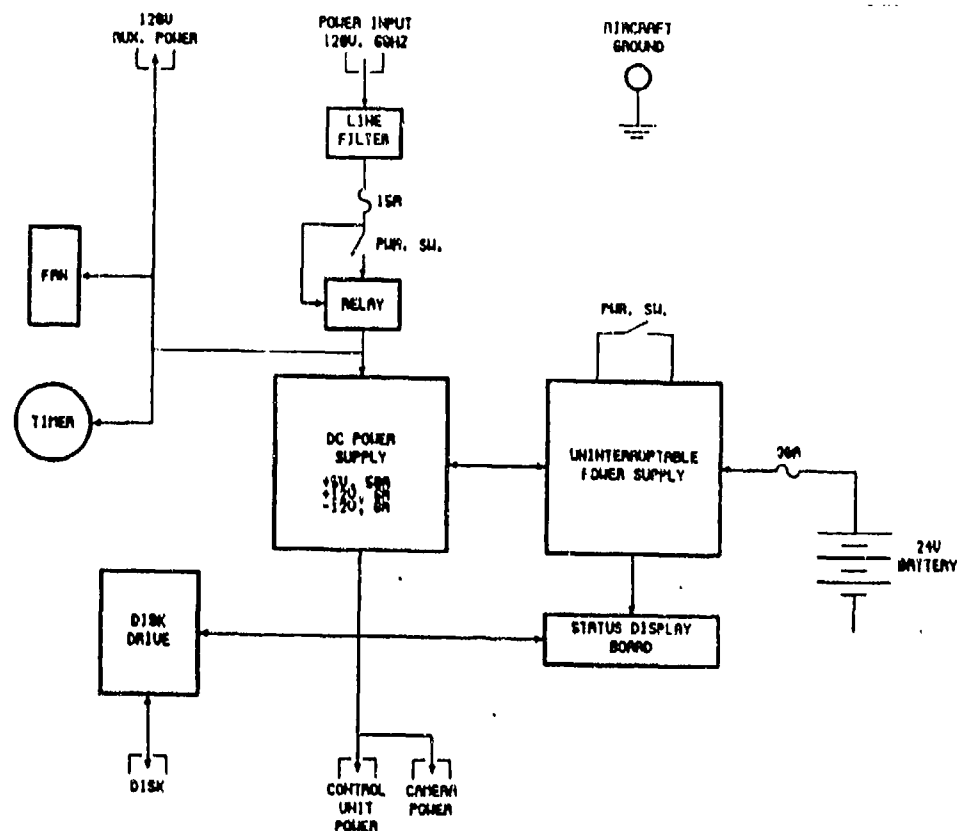


Figure 3-7. Power-unit block diagram

detection and transmission of a low-frequency (kilohertz) signal to the position sensing receivers mounted adjacent to the inspection area. In addition to these functional requirements, the specific design goals were to develop a probe that:

- Is relatively easy to hold for prolonged periods without undue operator fatigue;
- Permits a relatively fast scan coverage of the inspection surface;
- Provides for a fast and accurate target point determination.
- Provides for rapid changeout of probe-assembly hardware (i.e., search unit, delay tip, booted assembly, and probe handles);
- Places the position stylus transmitter up and out of the way of the operator's hand; and

- Accommodates scanning over relatively rough and irregular surface conditions (minor denting, chipped paint, etc.)

The resulting probe design included the probe body being shaped like a door knob, which is easy for the operator to simultaneously grip and apply pressure when scanning. The position stylus transmitter is located above and away from the search unit and operator's hand, thereby minimizing the effect of its presence on the inspection process. To facilitate through-transmission inspections, the probe body can be attached to a handle on the yoke or pole assemblies. The probe is easily and quickly attached to the probe handles by placing the probe in a stabilizer ring and securing with a single set screw. The stabilizer ring, in turn, is secured to the probe handles with two screws.

To accommodate scanning relatively irregular surfaces, a search-unit boot assembly may be used which replaces the stabilizer ring. The boot consists of a fluid layer captured between two polyurethane diaphragms. The upper diaphragm conforms to the search unit face, and the lower diaphragm conforms to surface irregularities.

In some circumstances, an inspection with a single probe (i.e., pulse-echo technique) may not be practical due to the complexity of the signal response from the structure or because of attenuation. Through transmission then may be the only alternative. In these instances, the transmitting and receiving search units must remain aligned on opposite sides of the structure. To accommodate this mode of inspection, a through-transmission yoke has been designed. Springs attached to the yoke arms maintain contact between the search units and inspection surface, and the probes are kept perpendicular to the inspection surface by the use of gimbed mountings.

To enable the examiner to inspect component surfaces oriented awkwardly (underside of surfaces, vertical surfaces), a pole assembly can be used. This assembly facilitates inspection of surfaces whose orientation would cause rapid fatigue. The pole assembly allows the examiner to keep wrists and hands at a comfortable angle and arms at a comfortable height.

(b) Position Sensing Assembly

The position sensing assembly supports two receivers used to determine the position of the inspection probe during data acquisition. The time-of-flight of a signal from the position stylus on the inspection probe is measured to each of the receivers, and a triangulation calculation determines the probe position. The position-sensing assembly is mounted to the inspection surface by four adjustable suction cups. The mounting and removal of the position sensing assembly is accomplished quickly with a spring-loaded vacuum make/break actuator.

Also, preamplifier circuitry is mounted on the position-sensing assembly to amplify signals from the inspection probe prior to transmission to the UT instrument. This reduces the effects of

electrical interference or signal distortion inherent in the transmission of a signal through a cable.

(5) Remote Monitor

The remote monitor consists of a small 10-inch diagonal screen, high-resolution color monitor with RGB connectors on the back panel. It is packaged in a rugged protective outer enclosure with removable end covers front and rear. Its purpose is to provide the operator with the UT waveform and instrument set up information along with coverage and flaw plots. This monitor, in conjunction with the keyboard, enables a single operator to perform an entire inspection from the remote inspection location. The remote monitor receives its RGB signals and 120V DC power from the rear of the system control unit.

(6) Printer

The selected printer, a Texas Instruments Model 850XLT, provides a hardcopy documentation capability for parameters, data tables, and plots. The unit selected is a high-speed impact type with high-resolution (144 x 144 dpi) raster graphics capability and an 8-inch print-line width. The printer is transported in a rugged suitcase-type enclosure with polyurethane foam cushioning. The printer may be used either in or out of the suitcase. It requires 120-VAC power, which can be obtained from the auxiliary plugs on the rear of the power-supply unit. Communications between the printer and the system control unit are done through an RS-232-C port on the front of the microcomputer. An impact printer was selected for ARIS, since this type of hardcopy is better suited to long-term storage without fading than thermal printers. It is also easier to reproduce with good quality. Also, no special paper requirements exist, making it easier to locate paper supplies when needed.

(7) Peripheral Storage Case

A suitcase-type enclosure with sculptured foam-cushion inserts is used to store loose peripheral items for shipment. These items include the position receiver assembly, transducer probe assembly and attachments, CCD sensor and lens assembly, keyboard, small tools, and operating manuals.

(8) Cable Storage Case

A deep suitcase-type enclosure is used to transport all system cables and batteries. These cables include the 25- and 50-ft UT, position-sensing cable bundle; remote keyboard and monitor cable; and all local system interconnect cables.

3.3.2 Software Design

The ARIS system software is highly modular in structure, permitting the system to be extremely versatile by accommodating a wide variety of composite-material UT inspection procedures. The system functional capabilities and operational procedures presented in Section 3 are fully supported. The software system is permanently resident in system

memory (EPROM-based) so that operation can commence upon initial power up. The software executes on a multi-processor (Motorola 68000 and 68010) VME-based bus architecture.

(1) Software Development Procedure

The ARIS system is EPROM-based and does not function as a software development system. For this reason, the software was developed and debugged using a standard Motorola VME-10 computer system. The software is written in Fortran 77 using a Compiler purchased from ABSOFT Inc. and designed for use with this type of processor. The operating system for both the development and target (ARIS) systems was provided using an appropriately sysgened version of Motorola's VersaDOS software.

During the software development cycle, programs were written and debugged on the Motorola VME-10 software development system. Extensive debugging of these programs can be performed because all of the peripheral devices associated with ARIS can also be connected to the VME-10 system. Following the VME-10 software testing, the programs were downloaded into temporary RAM in ARIS and debugged using the on-board Motorola VME Bug monitor program. Once the program execution was validated using the temporary RAM, the software was loaded into EPROM units for final testing in ARIS.

(2) Software Documentation

The ARIS software is documented in a document entitled, ARIS Programmer's Reference Manual. This 3-volume document contains all the information required to permit a detailed understanding of the system software. The material contained within this manual includes:

- (a) Functional flowcharts of all major software modules
- (b) Pseudo code documentation for each software program. (This item is used in place of detailed flowcharts as agreed to by SWRI and USAF.)
- (c) Source code listings of each software program
- (d) Algorithm definition section
- (e) File data structure definition
- (f) Device communication protocol section
- (g) System hierarchy calling structure diagram
- (h) Labeled common/subroutine cross-reference index

(3) System Software Structure

The ARIS software represents a hierarchical structure consisting of five major modules. The functional flowchart for this structure is shown in Figure 3-8. The highest element consists of the main menu-selection module called ARIS. This highest level module permits the operator to select any of the other four major modules existing at the second level of the structure. The function of each of these second-level major modules is discussed in detail in Section 3. When selected, each of these second-level modules produces a list of specific activities which, if chosen, execute at the third level in the hierarchical structure. These third-level options result in providing the functional capabilities of ARIS. The menu-driven hierarchical structure is shown in Figure 3-9.

The ARIS software system enables the operator to control the system by activating selected functional capabilities using a hierarchy of menus. At any level within the menu hierarchy, the operator is presented with a limited set of options corresponding to the type of function being performed. In each menu, selections are presented using easily understood language. The keyboard control key associated with any option can be easily deduced by noting the option number presented on the menu list. The menu hierarchy can be traversed in both directions and provides an orderly sequence by which to schedule and control activities.

The functional capabilities for each major module are described in detail earlier and are not repeated here. The following information presents the functional flowchart and associated block diagrams for each of the four major modules. The general flowcharts for each major program in ARIS are provided in the ARIS Programmer's Reference Manual.

3.4 System Operation

The ARIS unit is designed for the nondestructive evaluation (NDE) inspection of aircraft composite material structures using manual UT techniques. The system is intended to fulfill requirements providing automatic data collection and processing of UT and surface-position data obtained during manual UT inspection of specific aircraft components. The processing provides a real-time coverage/ flaw-map display so that the operator can deduce inspection progress and interpret inspection results. The system also provides archival storage of the processed data and off-line (non real-time) post-processing analysis capabilities.

Due to the diversity of composite-material structural complexity and shape, the system is designed to support three different operating modes. These modes of operation, which differ with respect to the procedures required and functions performed during data acquisition and processing, are explained in detail in the sections which follow.

3.4.1 On-Site Setup and Assembly

The entire system is shipped to a site location using thirteen enclosures. Each enclosure provides suitable protection for its

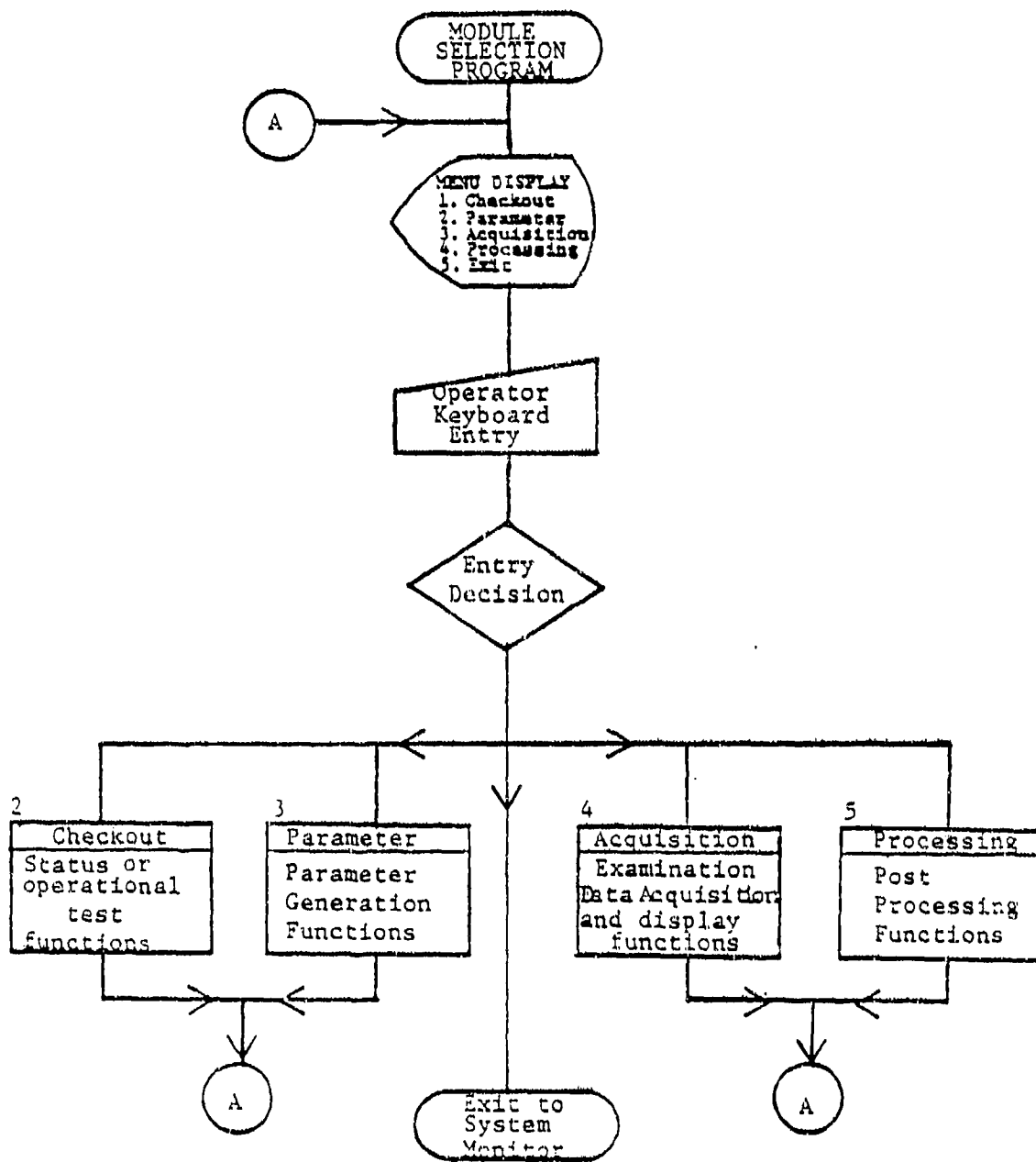


Figure 3-8. ARIS main-menu functional flowchart

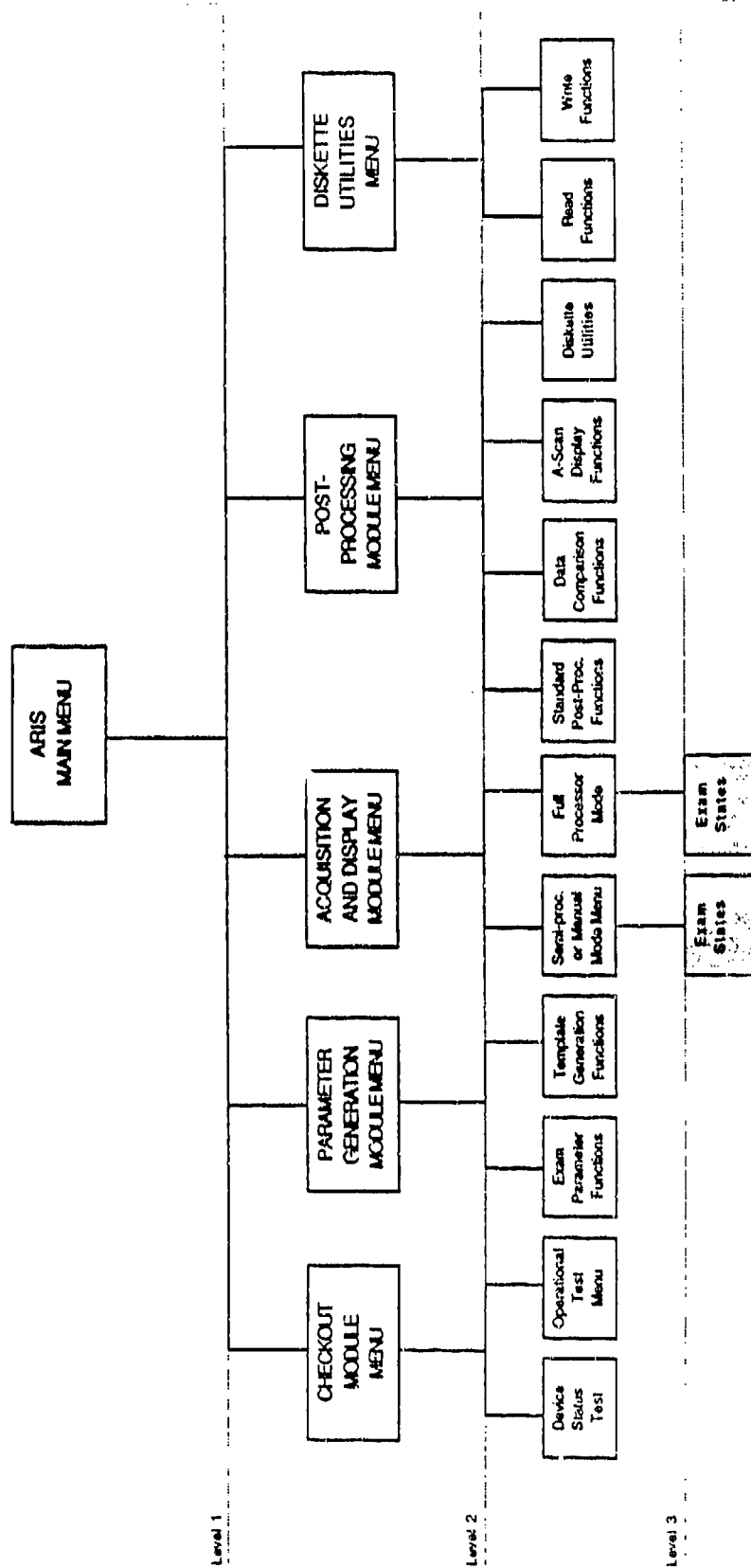


Figure 3-9. ARIS menu hierarchical structure

contents by using a custom fitted foam/rubber liner. The enclosures are configured so that each can be handcarried and shipped as airline luggage. The system enclosures exhibit the following features:

- (1) All peripheral accessory equipment for the system is stored within compartments (cutouts in the case foam liner) in the thirteen (13) enclosures. These items include all cables, transducers, transducer-holder units, delay lines, printer paper, couplant bottles, instruction and maintenance manuals, required tools, etc.
- (2) Each box has identification letters denoting the box contents.
- (3) The operators instruction manual includes a section for packing and shipping recommendations.
- (4) The number and type of tools required to perform assembly have been minimized. Any required tools have a specified storage location within a designated box.
- (5) The instruction manual denotes the storage location of any required tools.
- (6) The instruction manual itemizes each step required in order to perform the system assembly.
- (7) All detachable accessories (cables, equipment, etc.) are appropriately labeled with a permanently attached tag. These labels are referenced in the assembly instructions.
- (8) Each system accessory attachment location on every box is identified with a label denoting the name appropriate for the accessory.
- (9) Each accessory connector location on the boxes is visible to the operator so that proper mating can be verified. Every effort has been made to ensure that connection jacks and plugs are noninterchangeable so that incorrect hookup will not be possible.
- (10) The front and rear panels of the UT instrument enclosures and the system control enclosure are recessed to protect any switches, dials, digital readouts, or connector attachments.
- (11) Enclosures containing the UT instrument and system control and power supply electronics are mounted on a sturdy mobile cart. The cart is designed to minimize the probability of tipping and is easily disassembled for shipping. The cart includes large-diameter wheels to facilitate movement over hanger door tracks and

uneven road surfaces. A wet-weather cover (pull-over type) is also included on the cart to protect the equipment from rain during cart movement or storage.

- (12) The system CRT monitor may be placed on top of the mobile cart for local operation or at some suitable location near the component inspection area for remote operation.
- (13) The Sonic Digitizer is designed for direct mounting to the aircraft. Attachment will be made using four adjustable vacuum cups.
- (14) The video camera attaches to the UT instrument display-scope case using a small hood enclosure. When required, the camera can be positioned over the CRT display using the hood enclosure; or if not required, the camera/enclosure can be easily removed to give the operator an unobstructed view of the display.
- (15) The printer is in a separate box and is a desk-top type model operable either in or out of its shipping container as appropriate. Set up and use of the printer at the inspection site are optional. The printer provides an 8-inch width and is an impact (nonthermal) type.
- (16) The control keyboard can be placed on any suitable surface and is operable from the mobile cart or the remote inspection area. In this way, it can be conveniently located and not encumber the operator.

3.4.2 Operational Checkouts

Upon completion of the on-site setup and assembly activities, the operator can determine proper operation of each system component using the automated system-checkout capabilities incorporated into the system software. The operator's instruction manual contains instructions on all activities pertaining to equipment checkout.

3.4.3 System Operational Capabilities

The software control programs for ARIS are EPROM resident at all times. No diskette is required to execute these programs. The primary function of the diskettes is to allow initial system boot up and storage and retrieval of both parameters and processed data. A diskette utility module is provided to enable the operator to create parameter or processed data diskettes and to mount/dismount diskettes into the disk drive.

During system operation, the following standardized actions occur relative to operator input and system error-detection notification. For all operator system entry actions (except exam state selection), the system prompts the operator with a display specifying menu choices or a

question. Included in the prompt is a valid response guide enclosed in parentheses. Should the operator enter an invalid response, the system ignores the input, displays an invalid-entry error message, and repeats the request. In this manner, the system is protected from improper operator responses.

Additionally, during operation, if an error condition is detected by the system, the operator will be notified of the error condition, the probable cause and corrective action, and will be required to acknowledge the error by striking a key on the keyboard. Following operator acknowledgement of the error condition, the system resumes operation at the most recent operating condition which was unaffected by the error. In this way, error conditions don't hang the system but cause operator notification and acknowledgement actions to occur which return the system to a valid operating condition.

The ARIS is designed for operation in three modes--full processor control; semi-processor control; and manual.

(1) Processor Control Mode

The full processor-control mode involves conducting a component inspection with both the position and UT data acquired, processed, and displayed in real-time. The operator must perform all required parameter entry/recall activities prior to conducting the inspection. During the inspection, the operator may view the UT instrument A-scan and/or coverage/ flaw display. Also, processed data and/or operator-selected A-scans are saved for archival storage and subsequent off-line data analysis or display. The off-line (post processing) data analysis capability can be used to evaluate the current processed data set, or previously archived data can be recalled for analysis. Also, a data-comparison analysis can be performed between the current data set and an archived data set or between two archived data sets.

Prior to permitting operation in the full processor control mode, a device status check is performed and internally validated with a message to the operator reporting the pass/fail condition. Any discrepancies are reported to the operator so that corrective action can be initiated.

(2) Semi-Processor Control Mode

The semi-processor control mode involves conducting a component inspection with only the position data being acquired and processed to provide a coverage display. The operator views the UT data on the UT instrument screen or the system CRT display and monitors coverage on the system CRT monitor. In this mode of operation, the system is used to provide coverage information, but does not process any UT data to indicate flaws. No post processing or archival storage of UT data is possible. However, if specified by the operator, a copy of the coverage plot, any A-scan data, and the identification parameters can be saved as a record that the inspection was performed. The operator is required to comply with the procedures necessary to generate the scan-boundary tem-

plate, provide remote control of UT instrument parameter update or remote A-scan display, and permit archived coverage data storage if required.

In the semi-processor control mode, the operator is only required to define the scan-boundary template and conform to the procedures required to support the coverage plot generation and remote operation features. Additionally, the operator has the option to archive the coverage plot.

(3) Manual Control Mode

The manual control mode involves conducting a component inspection with no data being processed by the system. The operator is free to manipulate the transducer in any manner and views the ultrasonic signal on the UT instrument screen or system CRT monitor. No parameter entry or operational procedures need be complied with. If remote operation is involved, the system control unit must be operational to permit remote UT instrument adjustments or remote display control of the UT instrument A-scan. To permit this, the operator must conform to the procedures providing these control features. If a local type inspection operation is involved, the system control unit is not required to be powered.

(4) ARIS Main-Menu Control Options

The operator controls equipment operation by selecting options from the main ARIS control option menu displayed on the system CRT monitor. Selection of any of these system control options can occur at operator discretion. The System Checkout Module has been discussed above. Parameter generation can occur at any time desired by the operator prior to conducting the inspection; data acquisition and display can occur at any time, but require a complete set of parameters to be available (as discussed later); and post processing can occur at any time, but requires data from a previously completed inspection or archived data to be available (as discussed later). The mode of system operation (i.e., full processor, semi-processor, or manual control mode) is specified by the operator upon selection and entry into the data acquisition and display module.

(a) Parameter and Template Generation

The parameter- and template-generation module prompts the operator to enter specified inspection parameters and/or surface-boundary templates into the system. Operator input is performed using the keyboard and/or the stylus sound cursor (template input). The operator may enter one set of parameters and a template for the inspection to be performed, or any number of parameter sets or templates can be entered for storage and later recall. In the latter case, the parameter sets and templates are stored on diskette in catalog files. The parameter set catalog file is composed of sets of previously entered parameters and includes an index by which the operator can enter or retrieve a specified set. Likewise, the template catalog file is composed of existing templates and includes an index by which the operator can enter or retrieve a specified template.

Template generation is performed using the Sonic Digitizer (stylus sound cursor) and can be accomplished using component drawings depicting actual size (scale 1 to 1) or the actual component being inspected. The primary purpose of a template is to provide surface boundary regions defining areas requiring NDE inspection with a single set of UT instrument parameters. A template can consist of up to nine inspection regions. For each region, an enclosed polygon figure defined using the acoustic stylus probe assembly identifies the boundary of the region. Within each exam region, excluded zones can also be defined using an enclosed polygon within which the UT data will be ignored. The positional relationship between the Sonic Digitizer coordinate system and the physical coordinate system on the part being inspected is established using a set of target points. For any template, the operator can define between 2 and 10 target points. The identification number of a target point is determined by the operator. Additionally, each target point has a 32-character comment description associated with it so that, if necessary, it can be more clearly identified for future use. Once generated and identified, templates can be stored on diskette in a catalog file for subsequent retrieval and use.

The index list contains sequence numbers and operator-specified titles for up to 20 templates. The index is presented to the operator when any catalog storage or retrieval activity is required. The operator controls storage by specifying the file number and title. Retrieval is controlled by specifying the file number. The storage/retrieval mechanism protects the operator from inadvertently performing storage when either no template data have been entered or a duplicate (existing) file number is used. Also, the operator is protected from performing retrieval from a file number containing no previously stored template data. If a printer is available, a hardcopy printout of the template (scaled) can be generated. If a 1-to-1 scale presentation is desired, a series of hardcopy printouts can be generated and the combined.

Inspection parameter generation can be performed at any time prior to the actual inspection. This module permits parameters to be recalled from previous entry or to be initially entered. The operator may view the specified parameters and perform selected editing or updating. Four types of parameters can be entered: (1) identification parameters, which identify the aircraft and component being inspected; (2) component or sub-assembly parameters, which define the structure type, material composition and structure element to be inspected; (3) UT instrument parameters (up to 9 sets), which define the UT instrument settings conforming to the inspection procedure appropriate for the part (calibration settings); and (4) processing parameters, which define how the inspection data are to be processed and displayed. All parameters are checked for proper format and limit values upon initial entry or edit. Hardcopy printouts (see Table 3-1) can be generated for all parameters. Twenty complete sets can be stored on diskette in a catalog file. The storage and retrieval mechanism for inspection parameters is implemented using an index list identical in form and operation to that used for the template catalog file.

Table 3-1. ARIS PARAMETER-SET HARDCOPY DOCUMENT

Identification Parameters

Base Location:	Wright Patterson AFB
Type:	Plate
Tail Number:	N/A
Component:	ARIS Test Plate
Serial Number:	N/A
Sub-Assembly:	N/A
Inspection Date:	04/27/88
Inspector:	Dennis R. Hamlin
Comments:	Parameter set for use in generating a depth by color exam for ARIS test plate

Component Parameters

Structure Category:	Solid Composite Simulation
Structure Material:	Lucite with a series of bottom-drilled holes at varying depths and sizes
Structure Elem. Insp.:	Test Plate
Calibration Std. ID:	N/A

Processing Parameters

Display Type:	Gray Scale Time-Depth
Window Maximum:	0.40600 Inch
Window Minimum:	0.10600 Inch
LO Data Color:	Brightest
Comp. Rad. of Curvature:	0.00000 Inch
(convex: +, concave: -)	
UT Logic Level:	Positive
Transducer Freq./D.:	5 MHz 3/8"
Couplant Mode:	On
Transducer Serial:	SwRI 3349
Delay-Tip Type:	Flat (L)
Delay-Tip Len.:	0.5 Inch
Number Regions:	1

Prior to performing an inspection, all four parameter types must be entered. An internally controlled check flag is used to indicate to the system that all parameters have been entered.

Calibration of the UT instrument is performed by the operator using procedures appropriate for the component being inspected. The instrument gain, gate locations, gate lengths, amplitude thresholds, logic levels, pulser and receiver frequency tuning selections, damping, etc., settings determined during instrument calibration can be stored on diskette for subsequent recall and verification just prior to conducting the inspection.

(b) Real-Time Data Acquisition, Processing, and Display

During data acquisition and display, the operator is required to perform a sequence of procedural steps and is able to initiate or terminate a variety of system control features. The control software defines the procedure to be accomplished and then verifies that it was performed. For the full processor control mode, the system initiates each procedural step in the sequence shown below. In other modes, the operator can select the procedural step from a menu and, thereby, exercise selective control. The procedural steps include the following:

- (i) Initiation of parameter downloading or updating. The action performed is based on the processor control mode. For a full processor-control mode, all parameters are used. In this mode, the operator specifies the catalog file number of both the desired parameter set and template to be used for this inspection. If the template is not predefined but must be generated, then the template catalog file number can be omitted.

The operator may update the UT instrument parameters before initiating the inspection. This can be accomplished manually by adjusting settings on the UT instrument front panel or remotely by using proper command sequences on the operator keyboard. These fine-tuning adjustments may be required for amplitude sensitivity, time-base gate locations, etc. This final parameter set is recorded following update and stored with the inspection data following completion of the inspection.

- (ii) Template generation activity, if required. This feature is intended to support template generation while set up on the component being inspected. This feature would also be used to support semi-processor control mode operation or cases where recall of templates was not utilized.
- (iii) Entry of target points for the component being examined. These target points serve three purposes. First, the input target-point locations are used to align predefined templates to the component surface. Following target-point input, the system retrieves the predefined tem-

plate, performs a linear coordinate transformation, and displays the result on the system CRT monitor. A test is made to verify that all points composing the template reside within the valid sonic digitization area. If not, the operator is instructed to move the position receiver assembly, and the new location is verified. Both the template and digitizer boundary lines are displayed to assist the operator in determining how to relocate the position receiver assembly. Second, target points serve as alignment reference points for pinpointing flaw locations using 1-to-1 flaw map overlays of the component surface. Third, target points are used to perform positional alignment between two processed data sets prior to performing the data comparison analysis. Target-point definition may not be required (optional) for semi-processor and is not required in manual control mode operation.

- (iv) Initialization of inspection mode. The system is designed to accommodate either pulse-echo or through-transmission UT inspections. Data-display processing consists of either go-nogo or color-scale flaw-map presentations.

Inspection control states are provided by the system to facilitate performing the actual inspection. All of the control states are activated by the operator using appropriate key input from the keyboard. The intent of these control states is to permit the operator to indicate exam initiation and completion, repeat the current exam using the same parameter set and template, perform a different inspection using a different parameter set or template (or both) and to perform various support functions (UT parameter adjustment, template boundary adjustment, display adjustment, re-scan, etc.) which may assist the examiner in performing a more thorough inspection.

During an inspection, the system can be thought of as operating in one of nine possible states, as shown in Figure 3-10. The control states, discussed in the following list, provide specific functional capabilities. The operator is shown the current state on the display and may request a summary of available function states on the system CRT monitor (HELP screen). A summary of the state functions is shown in Figure 3-11. The function performed by each state when selected by the operator follows:

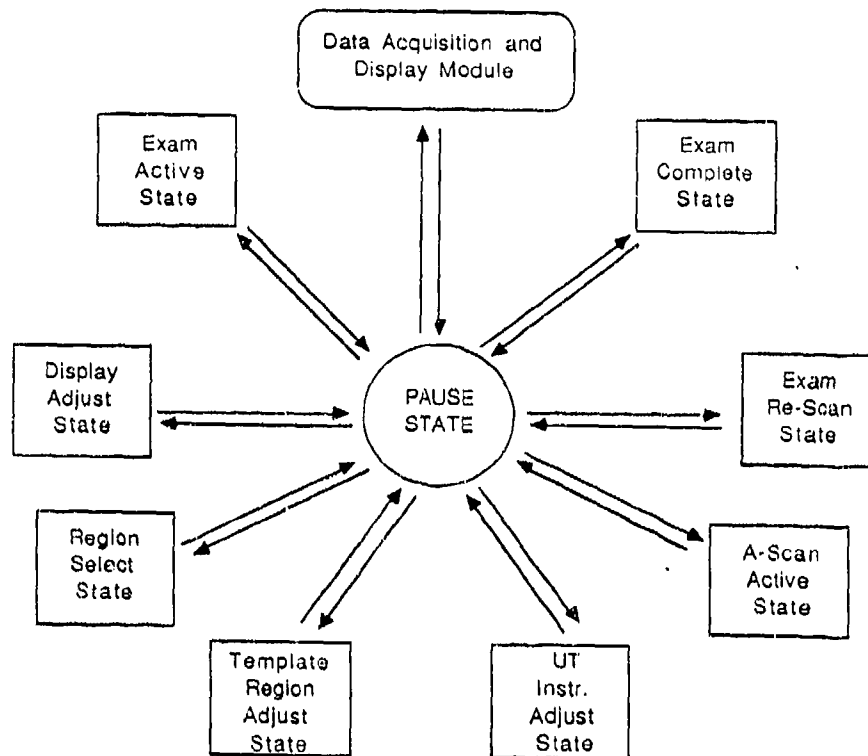


Figure 3-10. ARIS inspection operational states

- (i) Start Exam - permits the operator to notify the system that a new inspection is to be started. The system will initialize memory storage and screen display and then begins real-time processing and display activities.
- (ii) Continue Exam - permits the operator to continue a previously started exam. The system maintains existing memory storage and screen display information and then commences real-time processing and display activities.
- (iii) UT Adjustment - permits the operator to adjust the UT instrument parameter values. The inspection can then continue using the adjusted parameter set or default back to the original set at operator discretion.

Exam State									
	FAUSE	EXAM ACTIVE	EXAM COMPLETE	REGION SELECT	DISPLAY ADJUST	A-SCAN	UT INSTRUMENT ADJUST	TEMPLATE REGION ADJUST	EXAM RE-SCAN
F	Complete	Pause	Abort	Region Identified	Modify Window	A-Scan display	UT instrument parameter select (numerous sub-functions).	Boundary Erase Mode - Point Erase - Exit	Re-scan by region
U	Continue					A-Scan copy		Boundary Insert Mode - Point Insert - Exit	Re-scan by color level
M			Flaw/Map Hardcopy		Modify Threshold	A-Scan store			Re-scan by polygon area
C	Region Select		Processed Data Storage						
T	Display Adjust		Comment		Set original threshold on window				
I	A-Scan		Done						
D	UT-Instr.								
S	Exam Re-scan								

NOTE: The system CRT monitor control feature command is always active regardless of state.

Figure 3-11. ARIS inspection-state summary

- (iv) Display Adjust - permits the operator to adjust the data-display control parameters (threshold level, color range, etc.).
- (v) Template Adjust - permits the operator to adjust the inspection template boundaries as desired.
- (vi) Rescan Area - permits the operator to erase selected inspection data so that rescanning can occur. Data can be selected using a polygon area, color level, or region number.
- (vii) A-Scan Record - permits the operator to record selected A-scan waveform data, which then becomes part of the final inspection data. Up to 10 A-scans can be recorded.
- (viii) Region Select - permits the operator to initiate inspection of another region within the inspection template and downloads the USD-1 parameter set into the UT instrument.
- (ix) Finished - permits the operator to notify the system that the inspection is complete and perform various exam complete activities.

Upon completion of an inspection, the system sets a flag in memory to indicate that a complete processed data set exists. In this manner, if the operator elects to perform the post-processing functions, a check can be made by the system to determine that a valid data set exists prior to permitting the off-line data analysis.

(c) Post Processing

The post-processing module presents an option sub-menu on the system CRT monitor so that the operator can select the desired activity. The five sub-menu options permit diskette file I/O functions, standard processing functions, comparison processing functions, A-scan display and hardcopy functions, or return to the main ARIS control option menu.

A diskette file I/O option permits the operator to perform any required file-managing or file-handling functions necessary to support the desired post-processing activity. These file-management and handling functions include reading the required files, deleting files, renaming files, examining parameters within a file, or obtaining an index list of all files stored on the currently installed diskette. Using the file read function, the operator can load data required for the desired

processing activity. The specified data will be stored in memory for subsequent use by the processing routines.

The post-processing module is designed to operate on the current memory- resident processed data, archived processed data, or A-Scan data stored on diskette. Three types of processing are available in this module: standard, data comparison, or A-scan. The operator specifies the type of processing desired (standard, comparison, or A-scan) and is responsible for retrieving the required data from diskette prior to initiating the processing. The system verifies that the required data has been retrieved prior to initiating processing. If no data have been retrieved from diskette and standard processing is selected, the system checks to see that a completed data set is currently available. If the required data are not present, the operator is notified of this error and returned to the post-processing main menu.

The standard analysis allows the operator to define processing parameters which discriminate the data on the basis of position, amplitude, or time (depth), and then display the re-processed coverage/ flaw map on the CRT monitor. Data listings consisting of parameters, cartesian coordinates, amplitudes, and times can be obtained using these same discrimination parameters. The plotter can be used to provide a scaled hardcopy printout or to plot segments, which can be combined to produce a 1-to-1 flaw map plot. The data comparison capability can be used to compare two processed data sets as defined by the operator. These may be either one archived set and the current data set or two archived sets. If two archived sets are used, they must both be retrieved from diskette. One occupies the current inspection-set memory area, and the other occupies the previous inspection-set memory area. The operator is permitted to implement a difference analysis feature and view the result in either graphic or tabular listing form. This difference feature is displayed using a color-scale presentation representing the magnitude of the amplitude or time difference existing between the data sets for each display pixel. This type of display represents the difference between the two processed data sets. Positionally, the two data sets are aligned using the target points.

For A-scan processing, the operator is permitted to retrieve the desired data from diskette for display on the system CRT monitor. If specified, the operator can obtain hardcopy printouts of the A-Scans after they are retrieved from diskette and displayed. The operator may select any specific A-scan for presentation. Additionally, request an index listing (by position) of all A-scans currently in memory may be requested. Upon completion of the selected processing activity, return is made to the post-processing sub-menu.

(5) Operating and Nonoperating Environmental Specifications

The environmental specifications applicable to this system are provided in Military Specification IAW-MIL-T-28800B. In general, the range of environmental (operating and nonoperating) conditions specified in this mil spec are beyond what is available commercially for the types of instrumentation required for this system development effort.

The extent to which these conditions can be met with current commercially available equipment is as follows:

	<u>Mil Spec</u>	<u>Commercially Available</u>
Operating Temperature	-15 to 55°C	0 to 41°C
Nonoperating Temperature	-62 to 85°C	-10 to 68°C
Humidity	0 to 95-percent	20 to 80-percent